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Silicone Brake Fluid Performance Investigation

Prepared by
Ellen M. Purdy

Report Date
May 1992

92-15066



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United States Army
Belvoir Research, Development and Engineering Center
Fort Belvoir, Virginia 22060-5606

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REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188	
<small>Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Service, Direction of Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget Reduction Project (0704-0188), Washington, DC 20503.</small>				
1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE May 1992	3. REPORT TYPE AND DATES COVERED Final		
4. TITLE AND SUBTITLE Silicone Brake Fluid Performance Investigation (U)		5. FUNDING NUMBERS		
6. AUTHOR(S) Ellen M. Purdy		8. PERFORMING ORGANIZATION REPORT NUMBER 2505		
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Belvoir Research, Development and Engineering Center Logistics Equipment Directorate ATTN: STRBE-FLH Fort Belvoir, VA 22060-5606		10. SPONSORING/MONITORING AGENCY REPORT NUMBER		
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		11. SUPPLEMENTARY NOTES POC: Ellen M. Purdy, 703/704-3722		
12a. DISTRIBUTION/AVAILABILITY STATEMENT Distribution unlimited; approved for public release.		12b. DISTRIBUTION CODE		
13. ABSTRACT (Maximum 200 words) <p>Due to concerns of the Utah Army National Guard, field testing was conducted by BRDEC personnel to determine if silicone brake fluid was the cause of unexplained brake incidents. Air dissolved in silicone brake fluid was thought to come out of solution when the vehicles traveled at high altitudes. To test this, two 2 1/2-ton and two 5-ton trucks were filled with silicone brake fluid and conventional brake fluid (one of each) and instrumented with pressure transducers, thermocouples, and linear resistors. The trucks were then run over a pre-marked course that traveled to altitudes of 8,100 feet, with sensor readings taken during each prescribed stop.</p> <p>The data recorded during each stop revealed fluid pressure, pedal travel, and wheel cylinder temperature. Analysis of the data gave no indication of loss of fluid pressure due to air evolving from the silicone brake fluid while at high altitudes. Only one brake incident occurred during the testing. Analysis of the data recorded during the incident indicated a severe case of brake fade, or the loss of friction between the brake linings and the brake drum due to excessive use of the brakes. Instead of dropping down to a lower gear while traveling down the mountain, the driver tended to "ride the brakes" causing high temperatures that reduced the friction between the brake drums and the brake linings.</p>				
14. SUBJECT TERMS pedal travel, brake fade, air-hydraulic (a/h) cylinder, master cylinder, silicone, polyglycols, one-way valve vent, two-way valve vent			15. NUMBER OF PAGES 124	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT Unlimited	

Report Number 2505

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**US Army Belvoir RD&E Center
Logistics Equipment Directorate
Fort Belvoir, Virginia 22060-5606**

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Preface

The purpose of this endeavor was to investigate the possibility that silicone brake fluid (BFS) was not performing as intended in military air-over-hydraulic braking systems used in certain tactical vehicles. The investigation responded to a SMART initiative issued by the Utah Army National Guard. This initiative reported serious brake failures that had occurred in 2 1/2- and 5-ton trucks. Of particular concern was the capacity of BFS to contain up to 16% dissolved air. The field test that was conducted as a result of this SMART initiative was designed specifically to determine whether the amount of dissolved air in BFS affected braking in military vehicles under real operating conditions, and to gather data that characterized brake fluid performance.



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Section I

Background and Introduction

HISTORY OF PROBLEM

According to the Utah Army National Guard (UTARNG) and other National Guard units, the majority of their 2 1/2-ton and 5-ton trucks are outfitted with air-over-hydraulic braking. Although the trucks contain brake components that are nearly identical, the reported unexplained problems for each type of truck were different. In each case, however, the cause was perceived to be silicone brake fluid, MIL-B-46176 (BFS).

Unless otherwise identified as a mechanical or maintenance failure, the unexplained failures that occurred in 2 1/2-ton trucks (M109A3) typically involved wheel lock-up. UTARNG reported that drivers noticed the wheels dragging and then shortly thereafter, that they had locked up and would no longer move. As a quick remedy to the situation, the drivers opened the bleed valve at the wheel cylinder to allow the built-up pressure to dissipate. During that procedure, it was reported that the fluid foamed as it was released from the wheel cylinder.

In the 5-ton trucks (Dump Truck, M817), the unexplained brake failures simply involved loss of pedal resistance instead of wheel lock-up. Drivers typically reported that after allowing the trucks to sit idle for a period of time, even as short as overnight, upon pressing the brake pedal, a loss of fluid resistance occurred, and the pedal traveled further toward the floor than under normal braking. The problem was treated by simply pumping the brake pedal until full resistance was restored. From that point on, the brake system operated as intended, with no further loss of pedal.

This unexplained loss of pedal in the 5-ton trucks and the unexplained wheel lock-up in the 2 1/2-ton trucks were taken to be caused by BFS according to the National Guard units. Several complaints against BFS were included in the SMART initiative and are listed as follows:

- Silicone's affinity for air ... BFS absorbs air when under pressure during braking; then, when vehicle sits idle, the air is released.
- Silicone boils off at higher temperatures creating a void which is then replaced by air or water.
- Water gets into the brake system and forms globs in the silicone, and then boils when subjected to high temperatures.

Although not mentioned in the SMART initiative, another major concern of the National Guard units was the effect of varying altitudes. This goes hand in hand with the dissolved air issue in that the decreased pressures encountered at high altitudes causes the silicone fluid to release some of its air. This phenomenon was not previously considered a problem during the initial conversion to BFS, but was of primary concern to this investigation.

CONVERSION TO BFS

The Army chose to convert its vehicles to BFS to improve logistics and performance. Prior to the conversion, polyglycol brake fluid, meeting Federal Specification VV-B-680, and now referred to as DOT 3, was used in all hydraulic braking systems. Although it performed as required, several drawbacks prevented it from being the ideal fluid. Polyglycol tends to absorb water, thus causing severe corrosion. Also, polyglycol-based fluids have limited temperature ranges and no preservative properties. Therefore, the Army required a brake fluid for high temperatures, VV-B-680, a brake fluid for low temperatures, MIL-H-13910 (Arctic), as well as a preservative fluid, MIL-P-46046, for vehicle storage.¹

BFS (MIL-B-46176), however, can act as a preservative and can perform in both the high and low temperature ranges.² Probably the most significant advantage of BFS is that it is hydrophobic. This water resistant characteristic causes BFS to act as a natural corrosion inhibitor since BFS will not permit the absorption of water through unsealed portions of the brake system. Because BFS can act as a preservative and perform in extreme temperatures, only one type of brake fluid is required for all hydraulic systems in all types of environments.³

This ability of BFS to replace three previously used polyglycol fluids was projected to save the Army \$10 million from 1980 to 1990. BFS is now used in all military vehicles equipped with hydraulic braking (excluding administrative vehicles) and, except for the problems in 2 1/2- and 5-ton trucks, has performed acceptably since the initial conversion. Additional endorsement of BFS is provided by the the US Postal Service, which operates its fleet of vehicles with BFS and reports that use of BFS has increased the service life of wheel and master cylinders two to five times.

PURPOSE OF BFS TEST

As mentioned earlier, a primary concern was the effect of dissolved air in BFS on vehicle performance. Closely linked with this issue was the question of altitude effects. The field test was designed specifically to resolve these issues. An added factor incorporated into the test plan was the type of vent valve on the master cylinders in 5-ton truck air-over-hydraulic brake systems.

The amount of dissolved air in BFS is of paramount importance. According to the addendum to the SAE J1705, *Recommended Practice for Low Water Tolerant Brake Fluids*, testing revealed that BFS can contain up to $16\% \pm 3\%$ by volume of dissolved air at standard temperature and pressure.⁴ In contrast, polyglycol brake fluid has been found to contain only 3% to 5% dissolved air (see Appendix A). The more important question is whether or not a sufficient volume of dissolved air, and under what conditions, can be evolved from the fluid to cause brake failure.

In an attempt to identify these conditions, the investigation examined the possibility that increasing altitudes provided the environment under which dissolved air could be released from BFS. Dissolved gases are more likely to come out of solution when subjected to lower ambient pressures. The same effect is created when military vehicles operate over routes that involve high altitudes. The higher the altitude, the lower the atmospheric pressure, thus the tendency to evolve dissolved air is increased. Since a lack of hard data addressing this tendency existed, the test plan provided for collection of significant amounts of data that described the conditions to which BFS was subjected during normal and severe operation of the vehicle.

An added complication in determining the dissolved air effects arose from the type of vent valve used on the master cylinders in 5-ton trucks. The valve allows air to escape but not re-enter. This led to speculation that brake failures could be due to a vacuum that had been created by the one-way vent valve when air was forced out of the master cylinder due to fluid expansion. In order to isolate the altitude effects, the test plan called for testing to be conducted with and without the one-way valve.

AIR-OVER-HYDRAULIC BRAKE SYSTEM

The air-over-hydraulic type of braking system is unique in that it utilizes compressed air to act as a booster to hydraulic braking action. This particular system consists of a master cylinder, air-hydraulic (a/h) cylinder, wheel cylinders, and brake shoes and drums.

As in most brake drum systems, pistons in the wheel cylinders force the brake shoes against the brake drum causing it to slow its rotation and eventually stop. These pistons are activated by hydraulic pressure that originated from the pressure applied to the brake pedal. In air-over-hydraulic brakes, the brake pedal activates a push rod in the master cylinder (see Figure 1) which forces brake fluid into the a/h cylinder. This fluid activates a proportional valve that allows compressed air into the air portion of the a/h cylinder. This compressed air pushes

against the air piston which is approximately four times the size of the hydraulic piston. Since the hydraulic piston is mounted on the same rod as the air piston (see Figure 2), it is pushed with the same force. The force exerted on the brake fluid, however, is proportionally greater by a factor of 16. The new fluid pressure which extends to the wheel cylinder pistons is capable of reaching a maximum pressure of 1,900 psi.⁵

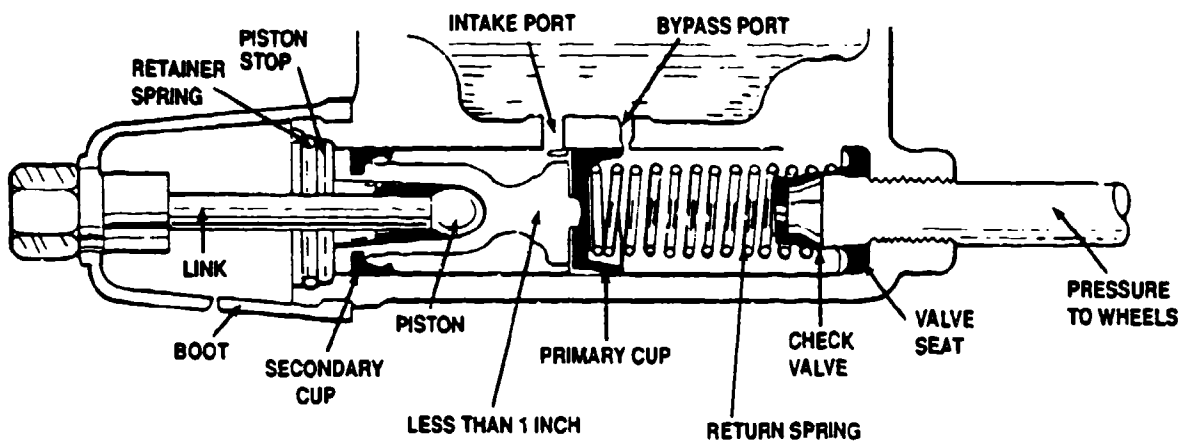


Figure 1. Inside View of Master Cylinder

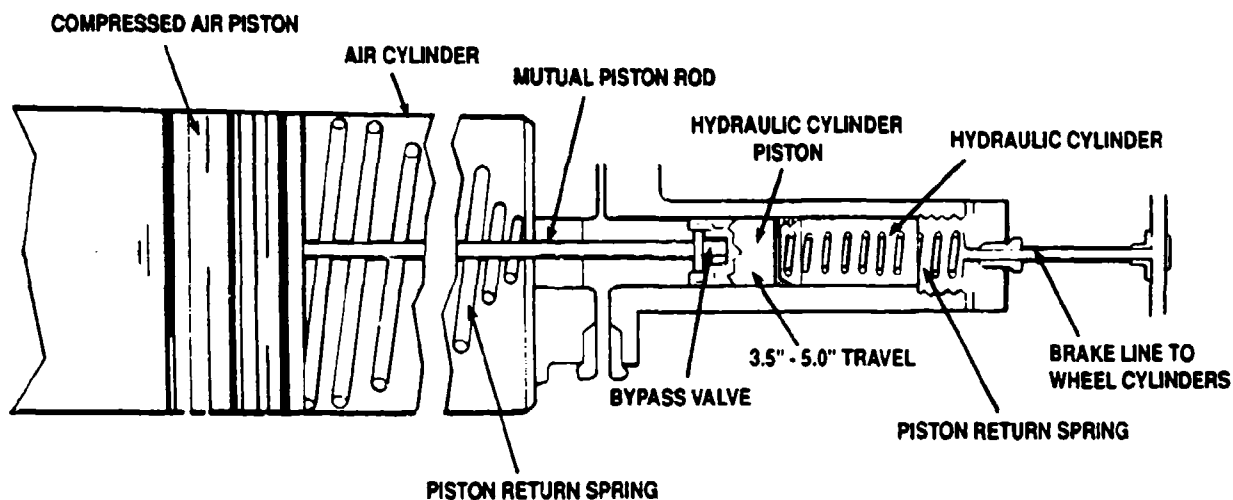


Figure 2. Inside View of Air-Hydraulic Cylinder

The sole function of the brake fluid is to transfer the force introduced to the brake system when the brake pedal is pushed. The brake fluid simply acts as a transfer medium such that the force that pushes the brake pedal is the same force (although amplified mechanically) that pushes the brake shoes against the brake drum. When fluid pressure is achieved in sufficient quantities (500 to 1,900 psi), the brake fluid has performed its intended function (see Appendix B).

SCOPE OF ACTUAL TESTING

The testing was not intended specifically to solve the unexplained brake failures in 2 1/2- and 5-ton trucks, but to determine if one aspect of the brake system—the brake fluid—contributed to the problem. The test was designed to characterize the physical behavior of the brake fluid during actual operation under actual conditions. By recording fluid temperatures and pressures while the brake system was performing properly, a comparison of the same parameters recorded during a malfunction would allow a greater understanding of the source of the failure. In addition, a record of fluid pressures would provide a means for determining if dissolved air affected braking performance and also whether or not altitude contributed to the reported brake failures.

Section II

Test Plan: BFS Performance Data Acquisition at High Altitudes

This test plan (see Appendix C) was designed to determine if BFS contributed to the reported brake failures in air-over-hydraulic brake systems. To accomplish this, four trucks (two 5-ton, two 2 1/2-ton) were instrumented with pressure, temperature, and pedal motion sensors to monitor the brake system behavior during actual operation of these vehicles. For each set of trucks, one used polyglycol and the other BFS. Each truck was outfitted with new master cylinders, air-hydraulic cylinders, and wheel cylinders prior to testing. The data monitored by the sensors was recorded in an on-board data logger and then transferred to a personal computer for later evaluation.

SYNOPSIS OF TEST PLAN

The test consisted of four phases. Phase I involved recording data while the trucks were operating at their lowest normal altitude (4,300 feet). The data collected at this altitude provided a baseline for comparison of other data. If changes in altitude affected braking performance, data recorded at different altitudes would differ from the baseline data. Phase II required the trucks to ascend a marked course, stopping at prescribed points, until an altitude of 8,100 feet was achieved. The continuous ascent provided the means of determining whether constantly changing altitude was a problem or whether the trucks required an "adjustment period" before the effects of altitude manifested themselves in the form of a brake failure. To further answer this "adjustment period" question, in Phase III the trucks were allowed to sit for 2 hours at the highest altitude before more baseline data was recorded. Data collected at this high altitude and compared to data collected at 4,300 feet would illustrate if the brake fluid was affected by the decreased pressure encountered at high altitudes. The final phase of the testing (Phase IV) required the trucks to descend the same marked course recording more data. This information would indicate if a continuous decrease in altitude was detrimental to brake system performance.

INSTRUMENTATION

The instrumentation of the trucks required two pressure transducers, four thermocouples, and one linear resistor for each truck. The two pressure transducers were installed to monitor the fluid pressure in the line between the master cylinder and the air-hydraulic cylinder (primary line) as well as the line from the air-hydraulic cylinder to the wheel cylinders (secondary line, see Figure 3). Fluid pressure in the primary line has a maximum pressure of 300 psi while fluid pressure in the secondary line has a maximum of 1,900 psi. Four thermocouples were used to monitor the front, middle, and rear wheel cylinder temperatures, as well as the temperature of the fluid in the master cylinder. Pedal travel that occurred during braking was measured with a linear resistor (see Figure 4) that was attached to the brake pedal linkage (see Appendix D).



Figure 3. Pressure Transducers in Fluid Lines



Figure 4. Linear Resistor Installed on Brake Pedal Linkage

DATA ACQUISITION

Each of these sensors generates a voltage that is proportional to the magnitude of the variable being measured. To collect the necessary data produced, the sensors were connected to a data logger (see Figure 5) that was programmed to scan the sensor input and record the voltage readings at specified time intervals. The same programming (see Appendix E) converted the voltage signals to pressure, temperature, and pedal travel information and stored it in memory. Since the data loggers have limited memory capacity, portable personal computers (PCs) (see Figure 6) loaded with customized software (see Appendix E) were used to down-load the data from the data loggers to memory in the PC. The same program that presides over the data transfer from the data logger to the PC was also developed to aid in evaluating the data. It reduced the data and reproduced it in graphic form so that approximately 200,000 data points were represented in a series of approximately 100 graphs.



Figure 5. Data Logger Wired to Sensors



Figure 6. Portable PC Linked to Data Logger

DISSOLVED AIR BENCH TEST

As an extension of the field testing that was conducted in Utah, a test plan was developed for laboratory analysis of the propensity of brake fluids to release dissolved air (see Appendix F). The test provides a qualitative measure of the effects of reduced pressure on both polyglycol and silicone brake fluid. In short, the test called for small flasks of the brake fluid to be placed in a vacuum oven and the pressure slowly dropped. Any appearance of bubbles was reported as well as any weight change. The same method was employed using a flask open to atmosphere and then a flask equipped with the one-way vent valve from the 5-ton truck's master cylinder.

The testing was conducted in the same four phases as the field test. Phase I consisted of recording weight at atmospheric pressure. The flask was then subjected to continuously decreasing pressures and, after reaching a final pressure, the flask was brought back to atmospheric pressure and weighed (Phase II). Any appearance of bubbles during this phase was noted. In Phase III, the pressure was dropped to its final value once again, and the flask was allowed to sit for 2 hours, during which the appearance of bubbles was again noted. After the time period expired, the flask was again weighed. Finally, in Phase IV, the flask was again brought to its lowest pressure, then the pressure was steadily increased and any appearance of bubbles recorded. The flask was weighed again one final time. Due to the nature of the vacuum oven, the recorded weights cannot be considered very accurate, as the time lag to bring the flask back to atmospheric pressure and to place it on the analytical balance would necessitate a slight change in weight.

This test for dissolved air does not address the issue of entrained air. Dissolved air involves air that is soluble on a molecular scale. Entrained air is simply air that has temporarily become trapped within the fluid. Previous testing reveals that silicone brake fluid releases trapped (entrained) air nearly twice as fast as polyglycol brake fluid (see Appendix G).

Section III

2 1/2-Ton Truck

Test Results and Analysis

LOW ALTITUDE BASELINE DATA

Baseline data for the 2 1/2-ton trucks was taken while traveling at a level altitude of 4,300 feet. The data loggers were programmed to begin taking readings whenever the brake light was activated if the power switch to the data logger was in the "on" position. The data logger would record sensor input every .3 second for a period of 18 seconds. For each brake application that was recorded, 480 data points were stored in memory. Figures 7 and 8 reveal typical "brake application signatures" in that the air-hydraulic and master cylinder fluid pressures, the pedal travel, and the point where the brake pedal or the data logger was disengaged were all plotted with respect to time. In each case, the two fluid pressures tracked closely with one another, as would be expected. The air-hydraulic pressure increases and decreases, although with a slight time lag, as the master cylinder pressure increases and decreases. The pedal travel also tracks with pressure; and as the fluid pressures decrease to their minimum values, the pedal returns to its upright position and the brake light shuts off.

Baseline data generated while traveling at low altitude are summarized in Table 1. Normal operating high and low values as well as the available operating ranges are included in the table.

Table 1. 2 1/2-Ton Truck, Low Altitude Baseline

BRAKE FLUID	SILICONE			POLYGLYCOL		
	Available Range	Operating Low	Operating High	Available Range	Operating Low	Operating High
Air/Hydraulic pressure (psi)	0 - 1,800	419	1,318	0 - 1,800	500	880
Master cylinder pressure (psi)	0 - 300	109	252	0 - 300	62	167
Pedal travel (inches)	0 - 7.5	4.14	5.34	0 - 7.25	2.37	3.2
Temperature (°F)	0 - 500	95	121	0 - 500	93	115

It can be seen, while traveling on level ground, the silicone truck requires an air-hydraulic pressure of 419 psi to stop. This is only 23% of the pressure available for stopping the truck. Roughly the same can be said for the polyglycol truck. Both trucks were easily stopped using a small percentage of the available braking power while traveling at 35 mph on level ground.

It is important to note the difference in pedal travel between the trucks. The silicone truck pedal typically requires between 4 and 5.5 inches of travel, yet the pedal can only travel up to 7.5 inches. The Technical Manual (TM) 9-2320-209-20 (page 281) for 2 1/2-ton trucks clearly states that when the pedal travel reaches 2 inches above the floor, the truck should be turned in for brake adjustment.⁶ Although the recorded pedal travel readings did not quite meet the criteria for necessary brake adjustment, they were close, and as such very nearly ready for maintenance even though the truck had just received a complete brake system overhaul the previous day.

CONTINUOUS ASCENT

Typical operating highs and lows for the continuous ascent were obtained by driving the trucks over a pre-specified course and stopping them at marked intervals. These intervals involved two complete stops at approximately every 500 feet in altitude. Figures 9 through 12 represent the brake signatures for both polyglycol and silicone at the start (5,300 feet) and finish (8,100 feet) of the course. Figures 9 and 10 are similar to Figures 7 and 8. Fluid pressures track with each other as well as with the pedal travel. Figures 11 and 12, however, differ in their overall shape. The most noticeable difference is the "brake status" line. In each case, the brake light seemed to have turned off before the brake pedal reached its normal position. This occurred because the data loggers were manually disengaged to prevent an additional 18 seconds of data being recorded. During some stops along the course, the drivers were unable to release the brake pedal and engage the hand brake before the data loggers were re-triggered to take data. To prevent the generation of excess data, the data loggers were disconnected from the brake light sensor. Recorded operating values are summarized in Table 2.

Table 2. 2 1/2-Ton Truck, Uprun

BRAKE FLUID	SILICONE			POLYGLYCOL		
	Available Range	Operating Low	Operating High	Available Range	Operating Low	Operating High
Air/Hydraulic pressure (psi)	0 - 1,800	400	753	0 - 1,800	691	838
Master cylinder pressure (psi)	0 - 300	77	167	0 - 300	130	174
Pedal travel (inches)	0 - 7.5	4.16	4.66	0 - 7.25	2.69	3.18
Temperature (°F)	0 - 500	120	129	0-500	121	135

Comparing data from Table 2 to the values listed in Table 1 reveals that traveling uphill is much easier on the brake system. The maximum air-hydraulic pressure required to stop the silicone truck was 753 psi which is 42% of the total available pressure. The polyglycol truck required a maximum pressure of 838 psi. Analysis of the raw data collected for the entire ascent reveals no evidence that brake performance is significantly affected by altitude changes for either the polyglycol or the silicone brake fluid.

It is evident, however, that the silicone truck has greater pedal travel than the polyglycol truck. The maximum pedal travel in the polyglycol truck is nearly 1 inch less than the minimum pedal travel in the silicone truck. Given that the misadjustment of the pedal occurred during testing, it is feasible that some of the brake problems reported can be attributed to the misadjustments on the brake systems during regular maintenance.

CONTINUOUS DESCENT

It was during the first descent down the marked course that braking problems arose. Table 3 lists the normal operating conditions of the brake system. The definition of normal in this case is based solely on driver information. Each stop that is represented in this table was considered by the drivers to be acceptable braking performance.

Table 3. 2 1/2-Ton Truck, Downrun

BRAKE FLUID	SILICONE			POLYGLYCOL		
	Available Range	Operating Low	Operating High	Available Range	Operating Low	Operating High
Air/Hydraulic pressure (psi)	0 - 1,800	549	999	0 - 1,800	691	1,328
Master cylinder pressure (psi)	0 - 300	137	174	0 - 300	169	249
Pedal travel (inches)	0 - 7.5	4.42	5.16	0 - 7.25	2.95	3.90
Temperature (°F)	0 - 500	125	154	0 - 500	127	154

According to Table 3, the maximum stopping pressures were considerably higher than those for the ascent and level ground. This is to be expected due to the added momentum gained from a downhill gradient. The table does not list the pressures recorded during the "brake failure" that occurred during testing, since it is only an accounting of normal braking activity. It does, however, reveal the significant increase in required fluid pressure as well as pedal travel. The polyglycol truck required a maximum stopping pressure of 1,328 psi to stop the truck, whereas the minimum pressure was 691 psi. This is a 52% increase in the required stopping pressure. Figures 13 and 14 illustrate the brake applications where substantially higher fluid pressures were required to stop the truck. The increase in pedal travel was also significantly greater than that observed for both the baseline phase as well as the continuous ascent. Taking this into account in addition to the high wheel cylinder temperatures, it can be seen that the polyglycol truck was also beginning to experience "brake fade," which is the loss of friction between the brake linings and the brake drum due to the high temperatures of the brake drums.

The "brake failure" that occurred in the silicone truck is also a case of brake fade, although more severe than that experienced by the polyglycol truck. Figures 15, 16, and 17 reveal the sequence of brake applications prior to and after the brake failure incident. Knowing that the silicone truck required only 500 psi to stop at the first marker, and that the required fluid pressures increased as the truck progressed down the mountain, the data clearly indicates that the friction between the brake lining and brake drum was steadily decreasing. Figure 15 illustrates the brake signature that required 999 psi to stop. In Figure 16, the brake signature for the "failure" shows that the fluid pressure to stop the truck maximized at 1,666 psi.

If a true brake failure had occurred due to the brake fluid, these pressures would not have been obtained. The fluid functions solely to transfer force to the wheel cylinders and, in the case of the "brake failure," nearly 1,700 psi was transferred. Comparison with previous data indicates that more than enough pressure was transmitted to stop the truck (see Table 4). The truck failed to stop easily because the gripping action of the brake lining had been decreased.

Table 4. 2 1/2-Ton Truck, Silicone Brake Application

BRAKE FLUID	SILICONE			POLYGLYCOL		
	Available Range	Operating Low	Operating High	Available Range	Operating Low	Operating High
Air/Hydraulic pressure (psi)	0 - 1,300	358	1,047	0 - 1,800	698	1,187
Master cylinder pressure (psi)	0 - 300	111	215	0 - 300	138	220
Pedal travel (inches)	0 - 7.5	3.80	4.36	0 - 7.25	2.87	3.67
Temperature (°F)	0 - 500	91	166	0 - 500	92	165

This loss of friction between the brake lining and the brake drum is a direct result of the high temperatures experienced by the brake drums. Temperature values recorded during the descent increase steadily as the truck traveled down the course. When the brakes failed, the temperature in the wheel cylinders had reached 160°F. Based on other recorded data, it can be estimated that the brake drum temperature was at least 100° higher. These high temperatures were a result of overstressed brakes. As the driver traversed the course, the observer reported that the driver's tendency was to ride the brakes to an extent instead of downshifting to allow the engine to slow the truck. If any vehicle were driven in this manner down a continuous grade, fade would definitely occur.

Figure 17 illustrates the next brake application after the truck was allowed to sit for a half hour to cool down. As can be seen, the fluid pressure required to stop the truck was back down to 863 psi. Subsequent stops required even less fluid pressure. If BFS was responsible for the poor brake performance, simply allowing the truck to sit and cool 20° would not restore the brakes, yet such was the case during testing. Given that the brakes performed adequately after allowing the truck to cool, indications are that causes other than BFS are responsible for this brake problem.

In order to further investigate the "brake failure" in the silicone truck, both vehicles were taken to Camp Williams for additional off-road testing. No adjustments to the brake systems were performed on either truck prior to the testing at Camp Williams. During the trip to the test site, brakes on both trucks operated correctly. The testing at Camp Williams, which was not included in the original test plan, called for the drivers to ride the brakes in order to increase the wheel cylinder temperatures. Upon reaching the target temperature of 160°F, drivers in both trucks noticed the odor of overheated brake linings. Just prior to this point, the polyglycol truck was exhibiting normal pedal travel of 1.7 to 3.2 inches (see Table 5), while the silicone truck typically used 4.01 to 4.07 inches of pedal travel. When both drivers reported a loss of pedal, the polyglycol truck was generating 1,824 psi in the air-hydraulic line with 3.92 inches of pedal travel, and the silicone truck was generating 1,702 psi in the fluid line with 5.75 inches of pedal travel. In each case, neither pedal was close to traveling its maximum distance and plenty of fluid pressure was supplied. Although not as severe as that experienced by the silicone truck the previous day, each truck exhibited the same phenomenon of brake fade.

Table 5. 2 1/2-Ton Truck, Riding Brakes

BRAKE FLUID	SILICONE			POLYGLYCOL		
	Available Range	Operating Low	Operating High	Available Range	Operating Low	Operating High
Air/Hydraulic pressure (psi)	0 - 1,800	397	1,698	0 - 1,800	555	1,485
Master cylinder pressure (psi)	0 - 300	72	306	0 - 300	124	278
Pedal travel (inches)	0 - 7.5	4.01	5.7	0 - 7.25	2.6	3.9
Temperature (°F)	0 - 500	140	175	0 - 500	145	165

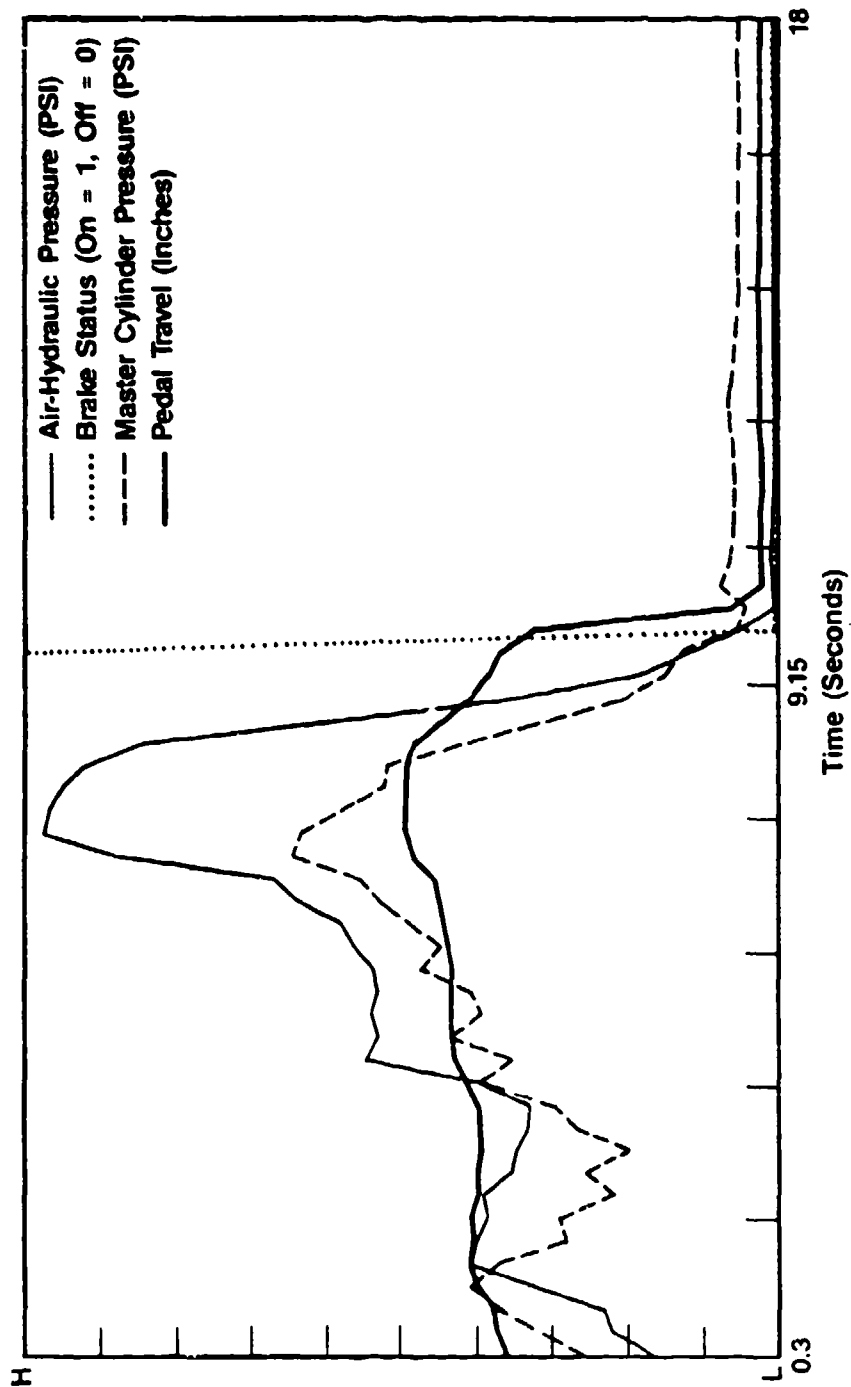


Figure 7. Typical 2 1/2-Ton Silicone Truck, Brake Signature (Baseline 4,300 feet)

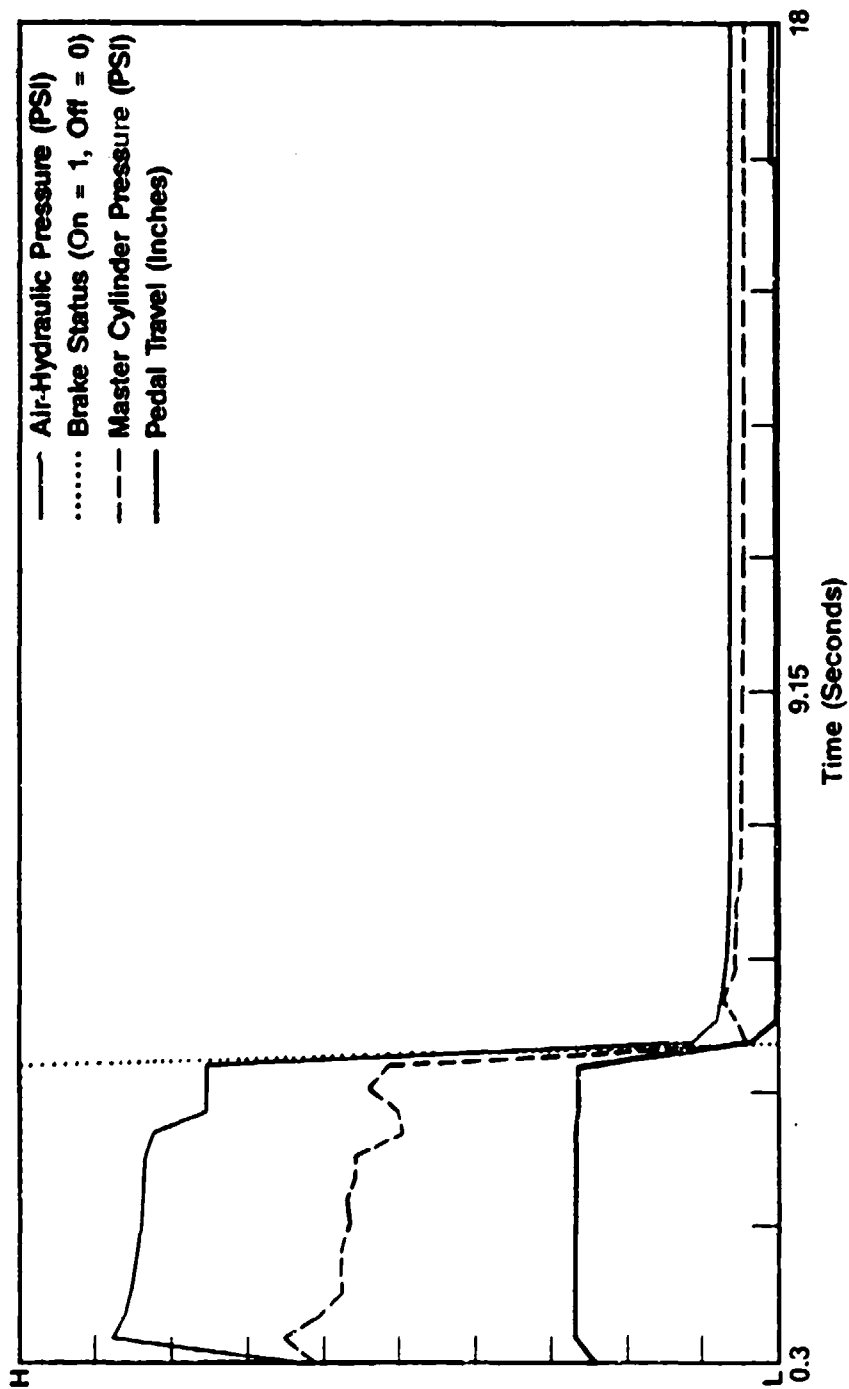


Figure 8. Typical 2 1/2-Ton Polyglycol Truck, Brake Signature (Baseline 4,300 feet)

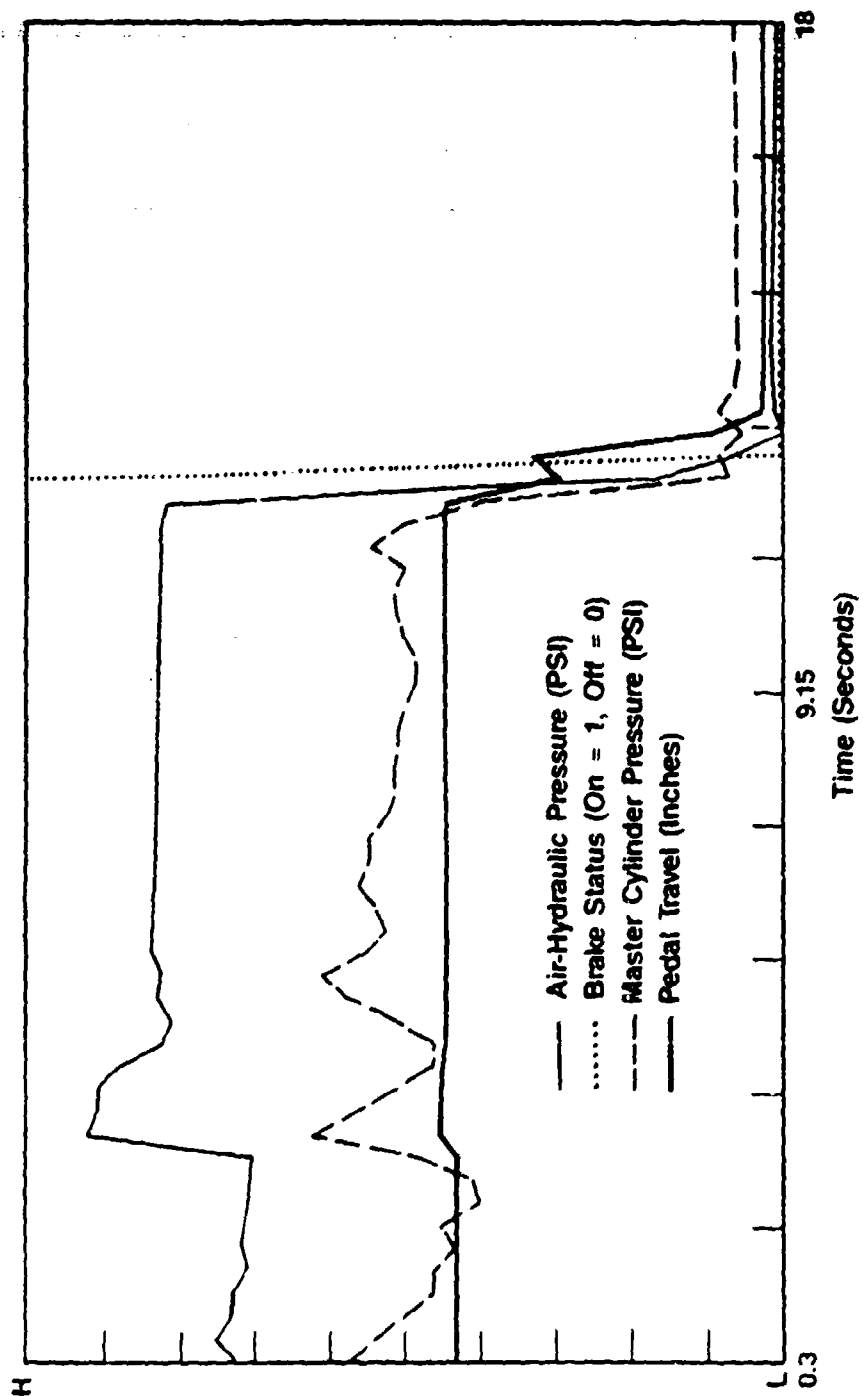


Figure 9. 2 1/2-Ton Silicone Truck (Uprun 5,300 feet)

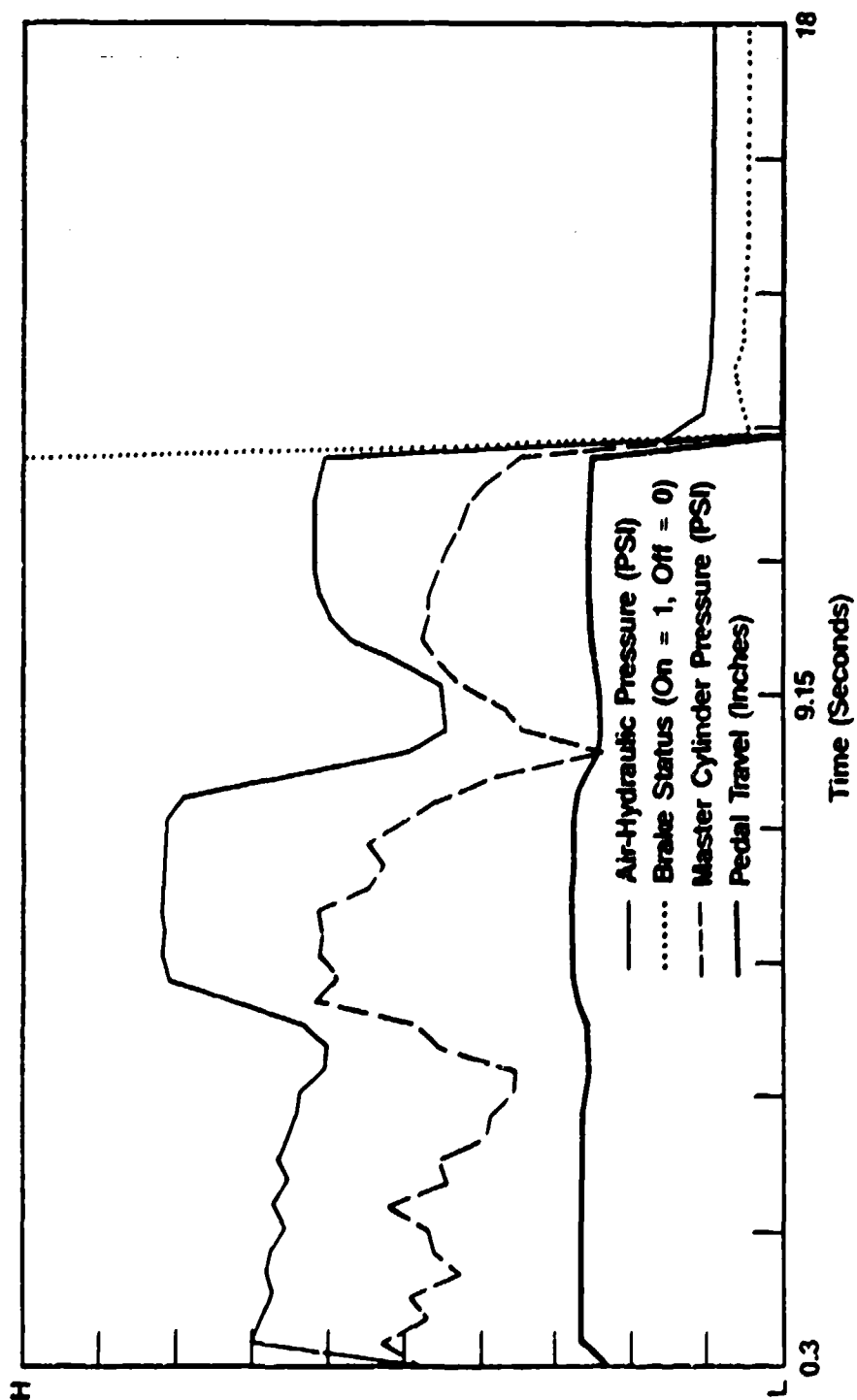


Figure 10. 2 1/2-Ton Polyglycol Truck (Uprun 5,300 feet)

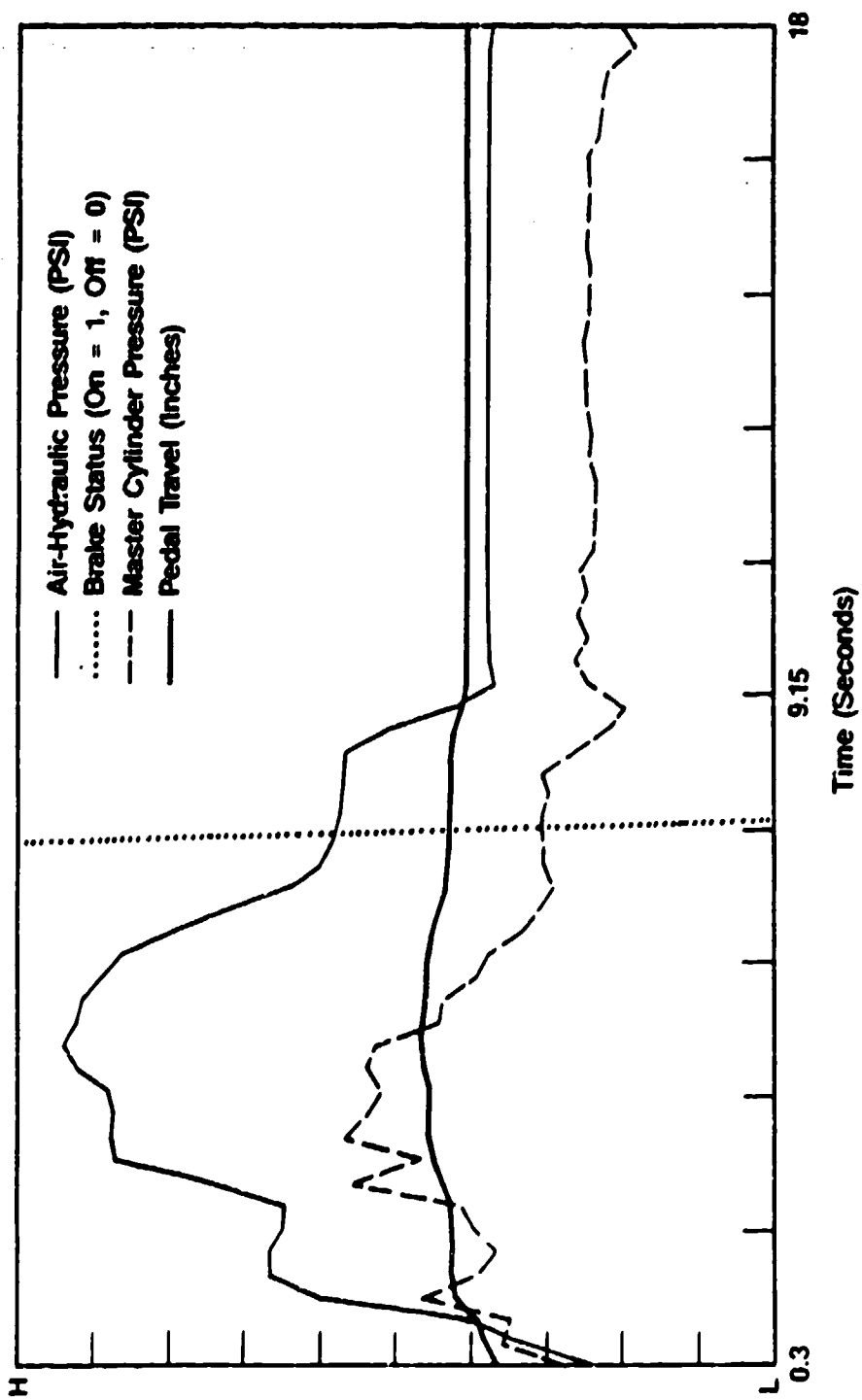


Figure 11. 2 1/2-Ton Silicone Truck (Uprun 8,100 feet)

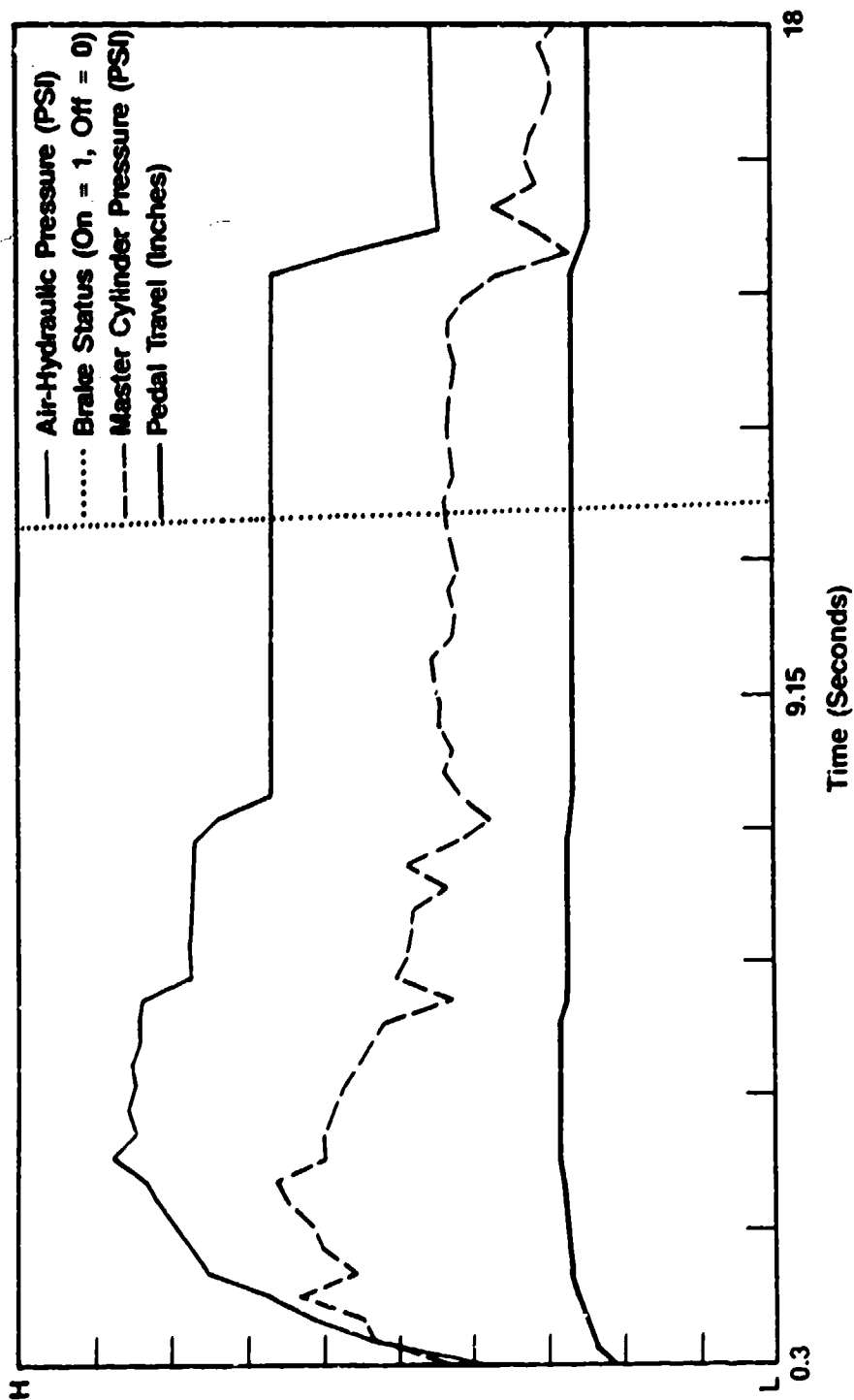


Figure 12. 2 1/2-Ton Polyglycol Truck (Uprun 8,100 feet)

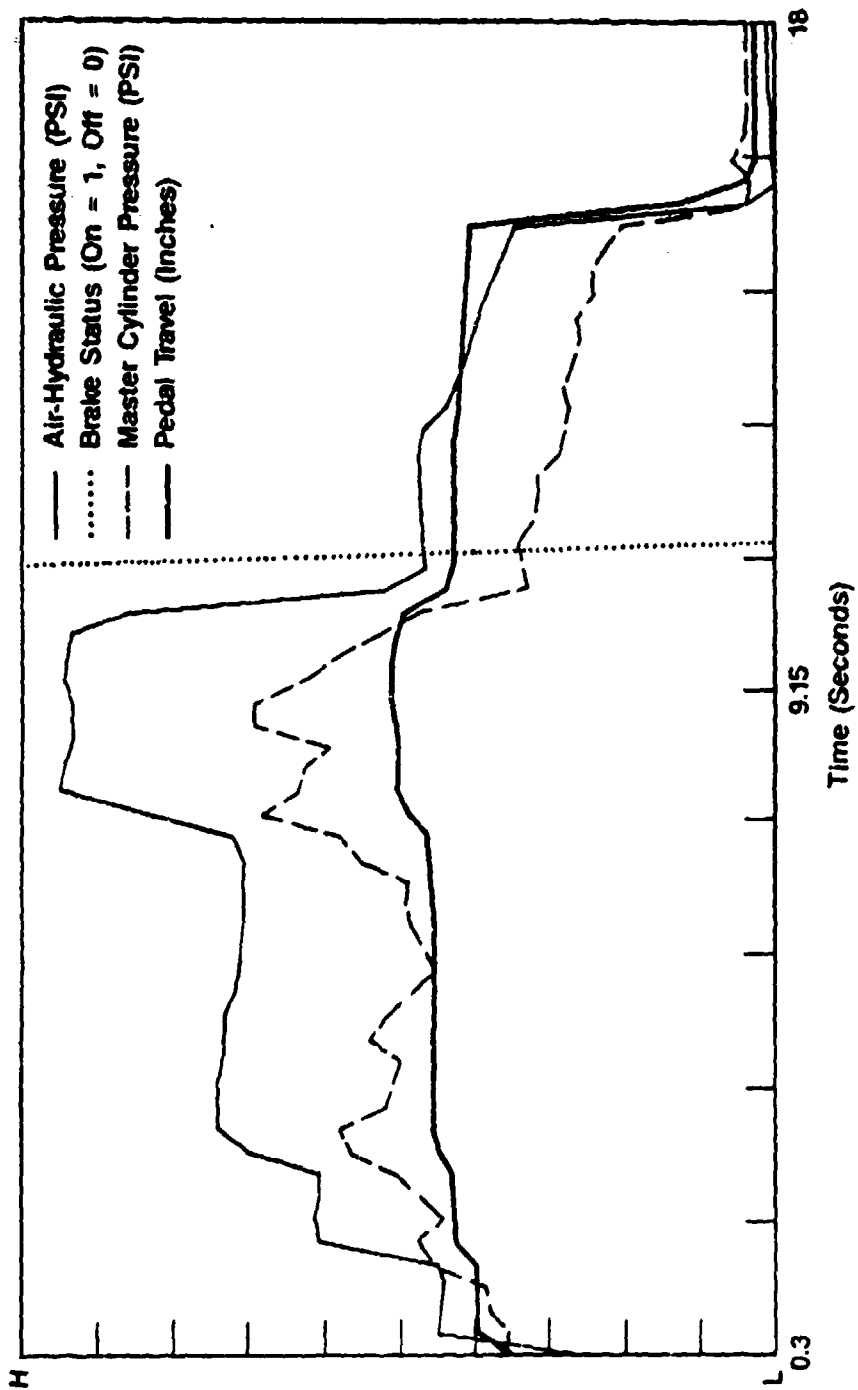


Figure 13. Higher Fluid Pressures and Increased Pedal Travel—Silicone

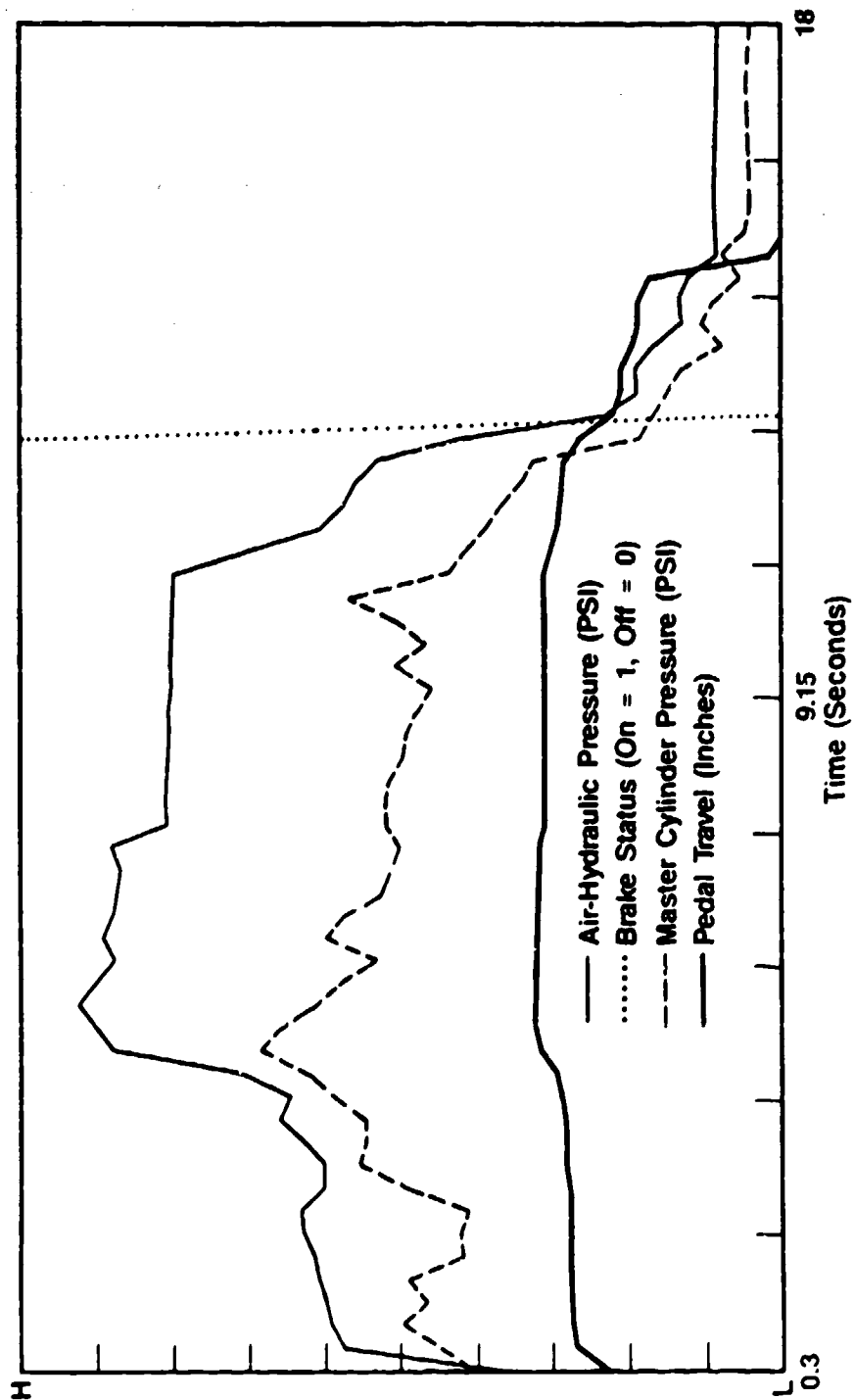


Figure 14. Higher Fluid Pressures and Increased Pedal Travel—Polyglycol

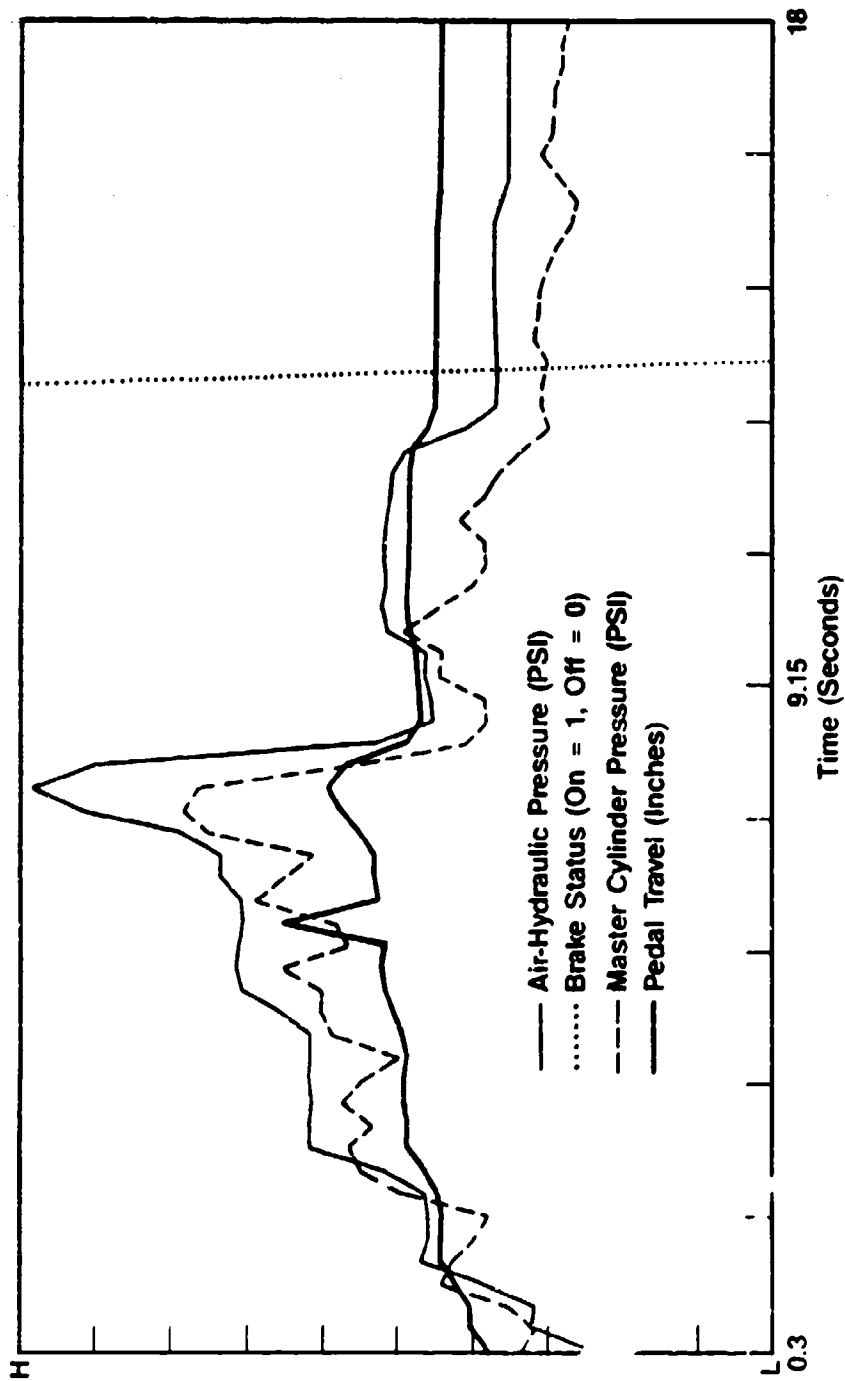


Figure 15. 2 1/2-Ton Silicone Truck, "Pre-Brake Failure"

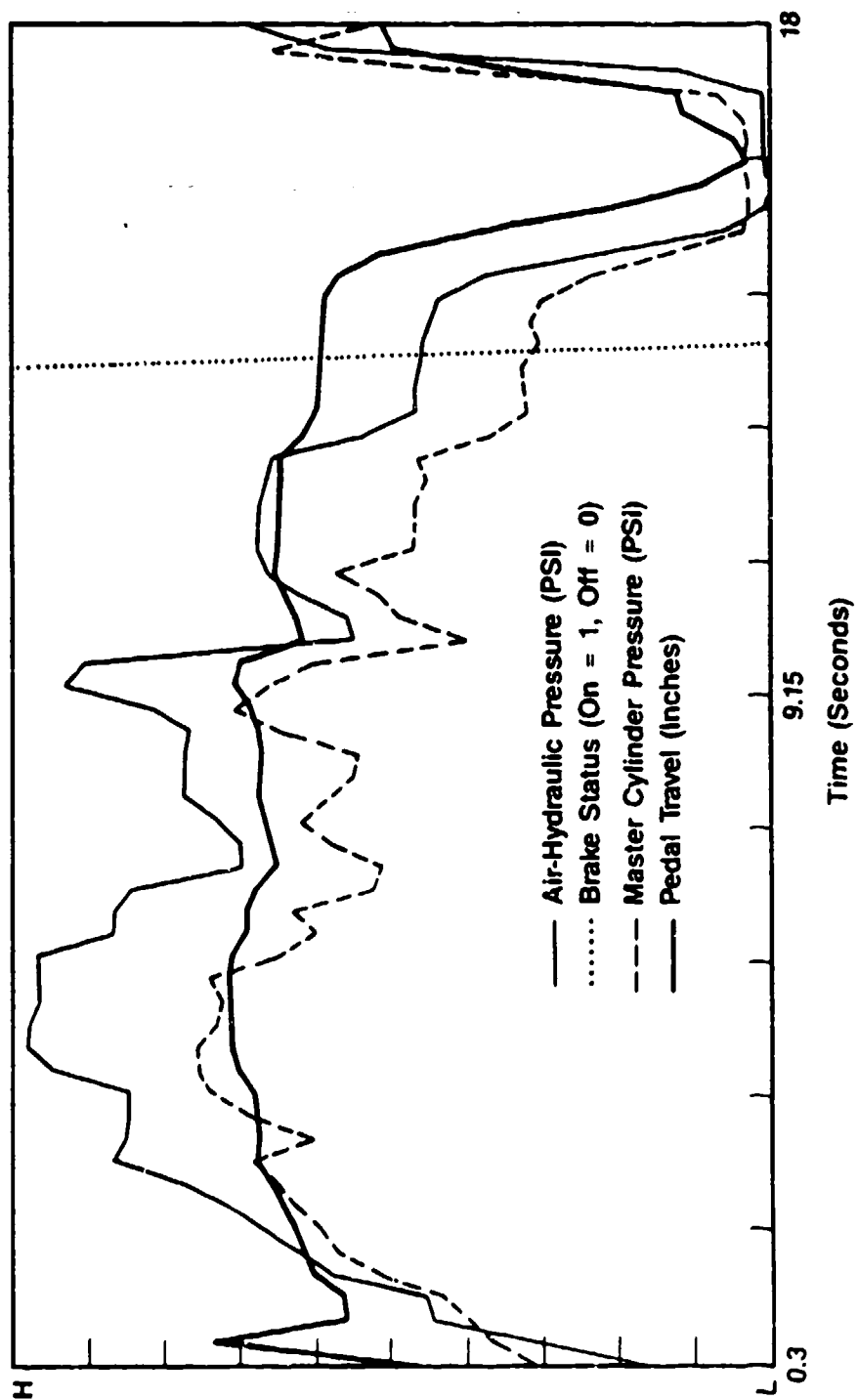


Figure 16. 2 1/2-Ton Silicone Truck, "Brake Failure"

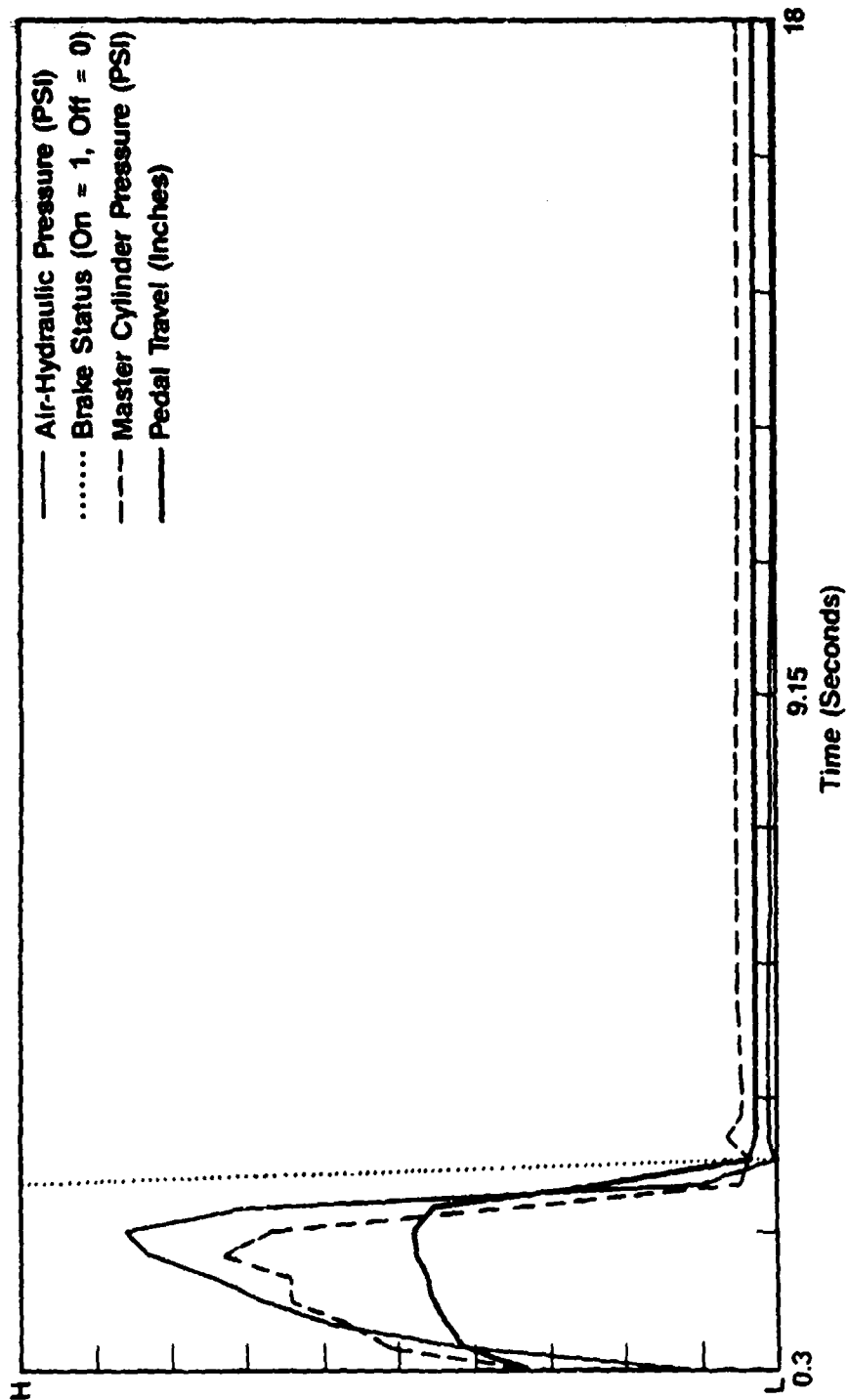


Figure 17. 2 1/2-Ton Silicone Truck, "Post-Brake Failure"

Section IV

5-Ton Truck Test

Results and Analysis

LOW ALTITUDE BASELINE TESTING

The low altitude baseline testing conducted for the 5-ton trucks was carried out following the final instrumentation and adjustments to the trucks. Figures 18 and 19 portray typical braking signatures for both polyglycol and silicone trucks. As expected, the plots show that the fluid pressures track exactly with pedal travel. Table 6 shows the normal operating parameters for each vehicle. Again, a significant difference between the amount of pedal travel in each truck can be observed. The silicone truck typically required 5.63 to 6.78 inches of pedal to generate 464 to 860 psi in the air-hydraulic fluid lines. The polyglycol truck only required 4.71 to 5.56 inches to generate 770 to 1,236 psi. In this particular case, the higher fluid pressures in the polyglycol truck are due most likely to driver performance. The fluid temperatures were relatively low indicating no undue stress on the brakes. The driver was probably pressing harder on the pedal than was actually required.

Table 6. 5-Ton Truck, Low Altitude Baseline

BRAKE FLUID	SILICONE			POLYGLYCOL		
	Available Range	Operating Low	Operating High	Available Range	Operating Low	Operating High
Air/Hydraulic pressure (psi)	0 - 1,800	464	860	0 - 1,800	770	1,236
Master cylinder pressure (psi)	0 - 300	59	83	0 - 300	72	103
Pedal travel (inches)	0 - 9	5.63	6.78	0 - 8.75	4.71	5.56
Temperature (°F)	0 - 500	81	108	0 - 500	79	97

PEDAL TRAVEL TESTING

When preparing to continue testing the following day, the pedals on both trucks were checked to see if the brakes were in proper condition. When pressing the pedal for the first time, the drivers reported increased pedal travel. In subsequent applications, however, the pedal traveled down less and less. In this respect, the brakes were "pumped back up." Table 7 reveals that although the pedal travel decreased to an extent, from 7.98 to 6.13 inches for the silicone truck and 5.29 to 4.69 for the polyglycol truck, in each case plenty of fluid pressure was generated. The driver of the silicone truck was able to deliver 1,182 to 1,675 psi to the wheel cylinders and the driver of the polyglycol truck was able to deliver 1,245 to 1,653 psi. Table 8 summarizes the normal operating values for the 5-ton truck with the two-way vent installed. The pedal travel values are similar to those values for the trucks when equipped with the normal one-way valve. The data substantiates the conclusion that the one-way vent valve in the master cylinder does not prevent normal braking.

Table 7. 5-Ton Truck, Pedal Travel

BRAKE FLUID	SILICONE			POLYGLYCOL		
	Available Range	Operating Low	Operating High	Available Range	Operating Low	Operating High
Air/Hydraulic pressure (psi)	0 - 1,800	1,182	1,675	0 - 1,800	1,245	1,653
Master cylinder pressure (psi)	0 - 300	111	242	0 - 300	90	182
Pedal travel (inches)	0 - 9	6.13	7.98	0 - 8.75	4.69	5.29
Temperature (°F)	0 - 500	83	84	0 - 500	62	67

Table 8. 5-Ton Truck, Pedal Travel With 2-Way Vent

BRAKE FLUID	SILICONE			POLYGLYCOL		
	Available Range	Operating Low	Operating High	Available Range	Operating Low	Operating High
Air/Hydraulic pressure (psi)	0 - 1,800	—	—	0 - 1,800	1,532	1,609
Master cylinder pressure (psi)	0 - 300	119	157	0 - 300	157	170
Pedal travel (inches)	0 - 9	6.12	7.75	0 - 8.75	5.07	5.56
Temperature (°F)	0 - 500	83	85	0 - 500	84	84

If the brake applications had been actual applications while the trucks were in motion, the trucks would have experienced no problems stopping. A comparison of Figures 20 and 21 with Figures 18 and 19 shows the close similarities between each set of braking applications. Except for high fluid pressures in the case of Figures 20 and 21, the brake signatures could be taken for those recorded while the trucks were in motion and brought to an actual stop.

While the cause for this pedal loss is not completely understood, a possible explanation is that the air compressor in the brake system has not completely built up sufficient pressure. Due to the proportional valve in the air-hydraulic cylinder, if the air compressor has not generated high enough pressure, the valve would have to open wider to allow the driver to feel the same amount of resistance he would normally expect. Since the valve is activated by the fluid pressure from the master cylinder, the more the driver presses the pedal, the wider the proportional valve opens. If the valve opens 50% and the air pressure is only 85 psi, less fluid pressure is generated than when the valve opens 50% and the air pressure is 120 psi. To compensate, the driver presses the pedal further than normal, because the opposing force that is exerted by the fluid on the pedal is less than it would be if full air pressure were available.

CONTINUOUS ASCENT

After the "pumping up" process, the driver felt confident enough with the brake system to continue the testing. During the continuous ascent phase, no abnormal braking action was recorded. Table 9 shows the lower fluid pressures required to stop the trucks. In each case, between 200 and 600 psi was generated. Again, values for the trucks equipped with the one-way valve are comparable to values for the truck with the two-way venting (Table 10). Figures 22 through 26 illustrate that few differences in brake system behavior manifested themselves during the trip up the canyon. Data recorded during this phase of the test suggests that altitude has no significant effect on BFS or its performance within the air-hydraulic braking system.

Table 9. 5-Ton Truck, Uprun

BRAKE FLUID	SILICONE			POLYGLYCOL		
	Available Range	Operating Low	Operating High	Available Range	Operating Low	Operating High
Air/Hydraulic pressure (psi)	0 - 1,800	245	572	0 - 1,800	245	572
Master cylinder pressure (psi)	0 - 300	45	58	0 - 300	45	58
Pedal travel (inches)	0 - 9	5.37	6.29	0 - 8.75	5.08	5.95
Temperature (°F)	0 - 500	86	134	0 - 500	82	133

Table 10. 5-Ton Truck, Uprun With 2-Way Vent

BRAKE FLUID	SILICONE			POLYGLYCOL		
	Available Range	Operating Low	Operating High	Available Range	Operating Low	Operating High
Air/Hydraulic pressure (psi)	0 - 1,800	—	—	0 - 1,800	440	648
Master cylinder pressure (psi)	0 - 300	42	56	0 - 300	57	69
Pedal travel (inches)	0 - 9	4.92	6.3	0 - 8.75	4.09	4.43
Temperature (°F)	0 - 500	80	107	0 - 500	81	95

HIGH ALTITUDE BASELINE

Tables 11 and 12 show the normal operating values when the vehicles were traveling at a constant high altitude. Comparison between the two tables shows no difference due to the venting of the system. Comparison of these tables with Table 6 (low altitude baseline) shows that the values are within the same range and actually somewhat lower in magnitude. If altitude were a problem for the brake system or fluid, a change in pedal travel would be observed. Lower fluid pressures accompanied by increased pedal travel would result if altitude affected braking performance.

Table 11. 5-Ton Truck, High Altitude Baseline

BRAKE FLUID	SILICONE			POLYGLYCOL		
	Available Range	Operating Low	Operating High	Available Range	Operating Low	Operating High
Air/Hydraulic pressure (psi)	0 - 1,800	270	502	0 - 1,800	523	809
Master cylinder pressure (psi)	0 - 300	46	68	0 - 300	58	65
Pedal travel (inches)	0 - 9	5.26	6.02	0 - 8.75	4.21	4.75
Temperature (°F)	0 - 500	80	103	0 - 500	65	74

Table 12. 5-Ton Truck, High Altitude Baseline With 2-Way Vent

BRAKE FLUID	SILICONE			POLYGLYCOL		
	Available Range	Operating Low	Operating High	Available Range	Operating Low	Operating High
Air/Hydraulic Pressure (psi)	0 - 1,800	—	—	0 - 1,800	439	702
Master cylinder pressure (psi)	0 - 300	18	64	0 - 300	58	75
Pedal travel (inches)	0 - 9	5.2	6.03	0 - 8.75	4.12	4.54
Temperature (°F)	0 - 500	78	93	0 - 500	78	88

Figures 26 through 29 show normal brake signatures for high altitude operation with and without the one-way valve. In each signature, the fluid pressures track with each other as well as with pedal travel.

CONTINUOUS DESCENT

Fluid pressures remained consistent and on the low side during the continuous descent of the 5-ton trucks both with and without the one-way valve. Looking at Table 13, it is evident that only 293 to 498 psi in the air-hydraulic line was required to stop the silicone truck with the one-way valve. Nearly the same pressures were required by the polyglycol truck. Table 14 reveals that roughly the same fluid pressures were sufficient when trying to stop the trucks with two-way venting.

Table 13. 5-Ton Truck, Downrun

BRAKE FLUID	SILICONE			POLYGLYCOL		
	Available Range	Operating Low	Operating High	Available Range	Operating Low	Operating High
Air/Hydraulic pressure (psi)	0 - 1,800	293	498	0 - 1,800	235	540
Master cylinder pressure (psi)	0 - 300	51	60	0 - 300	28	65
Pedal travel (inches)	0 - 9	5.45	5.92	0 - 8.75	5.14	5.85
Temperature (°F)	0 - 500	91	132	0 - 500	83	120

Table 14. 5-Ton Truck, Downrun With 2-Way Vent

BRAKE FLUID	SILICONE			POLYGLYCOL		
	Available Range	Operating Low	Operating High	Available Range	Operating Low	Operating High
Air/Hydraulic pressure (psi)	0 - 1,800	—	—	0 - 1,800	540	617
Master cylinder pressure (psi)	0 - 300	46	64	0 - 300	61	69
Pedal travel (inches)	0 - 9	5.35	6.08	0 - 8.75	4.13	4.34
Temperature (°F)	0 - 500	89	129	0 - 500	93	108

The descents for both trucks occurred with no braking problems. This supports the case for brake fade that occurred in the 2 1/2 ton truck earlier in the test. While the 5 ton trucks were traveling down the hill, the drivers ensured that they did not ride the brakes and down shifted to allow the engine to slow the vehicles. Given that the trucks were driven in this manner, maximum fluid temperatures of only 130°F were recorded. In addition, since the fluid temperatures remained fairly low, conditions conducive to brake fade did not occur. Figures 30 through 33 show typical brake signatures, indicating that the brake systems performed correctly at high and low altitudes.

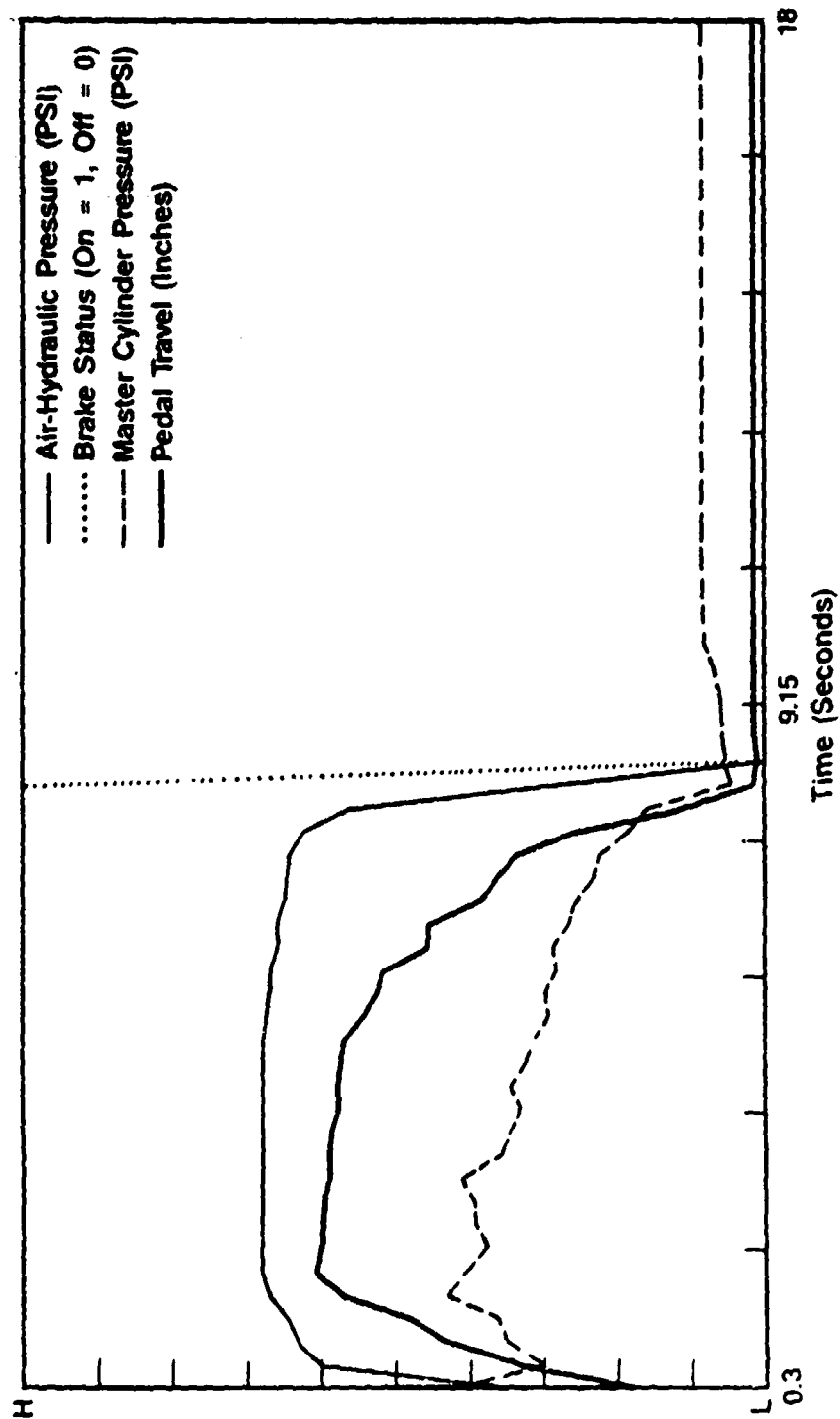


Figure 18. Typical 5-Ton Silicone Truck, Brake Signature

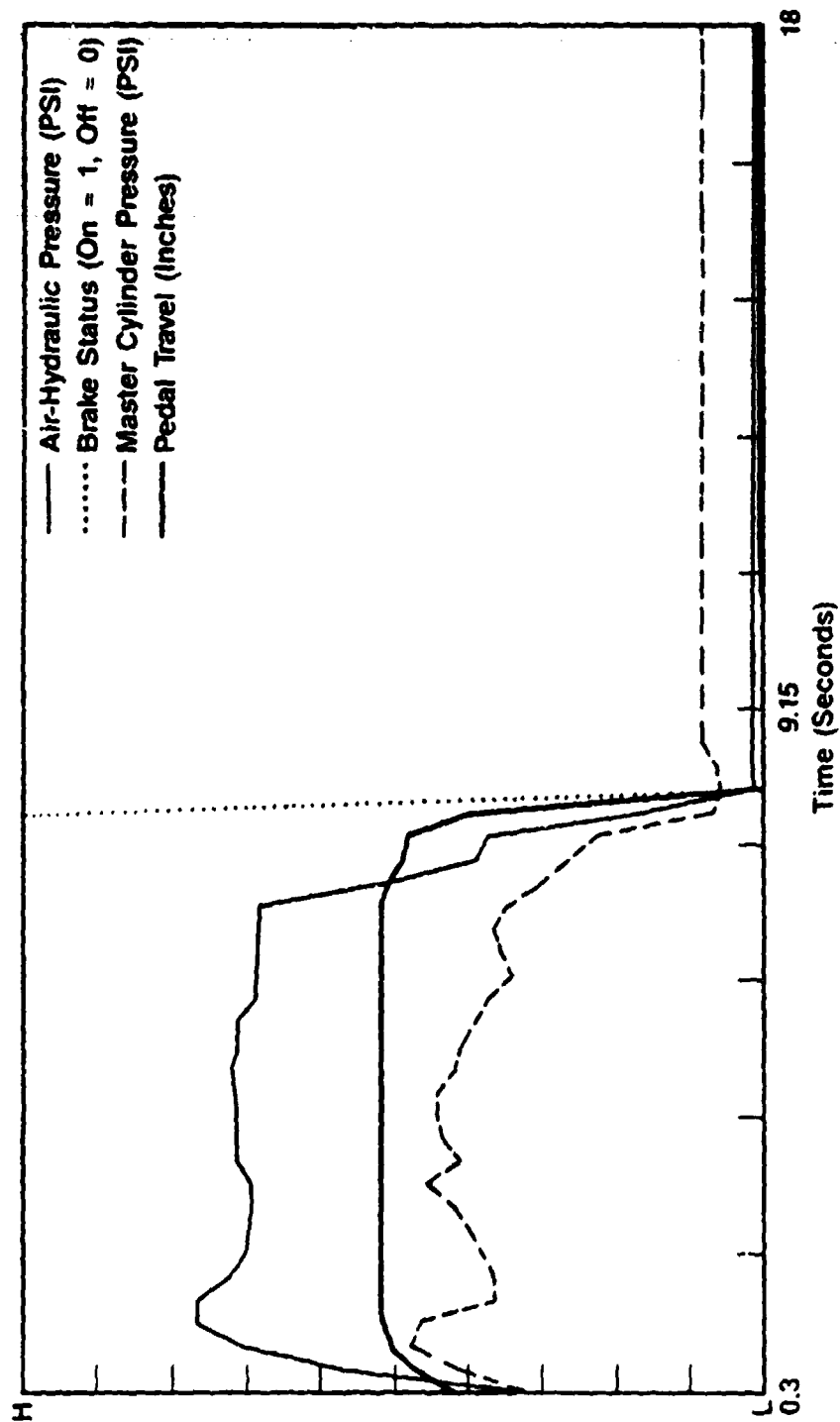


Figure 19. Typical 5-Ton Polyglycol Truck, Brake Signature

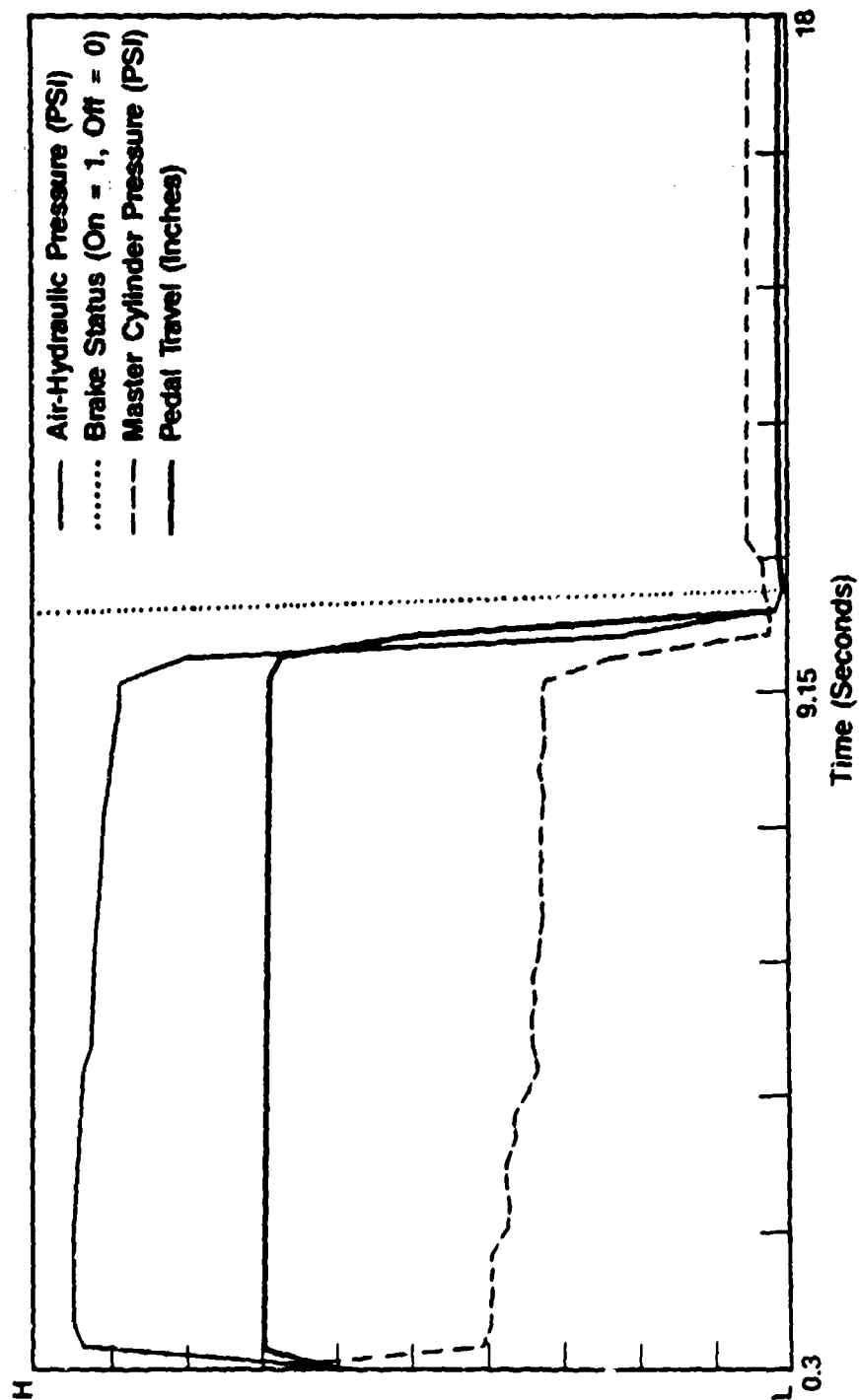


Figure 20. 5-Ton Silicone Truck Pedal Travel

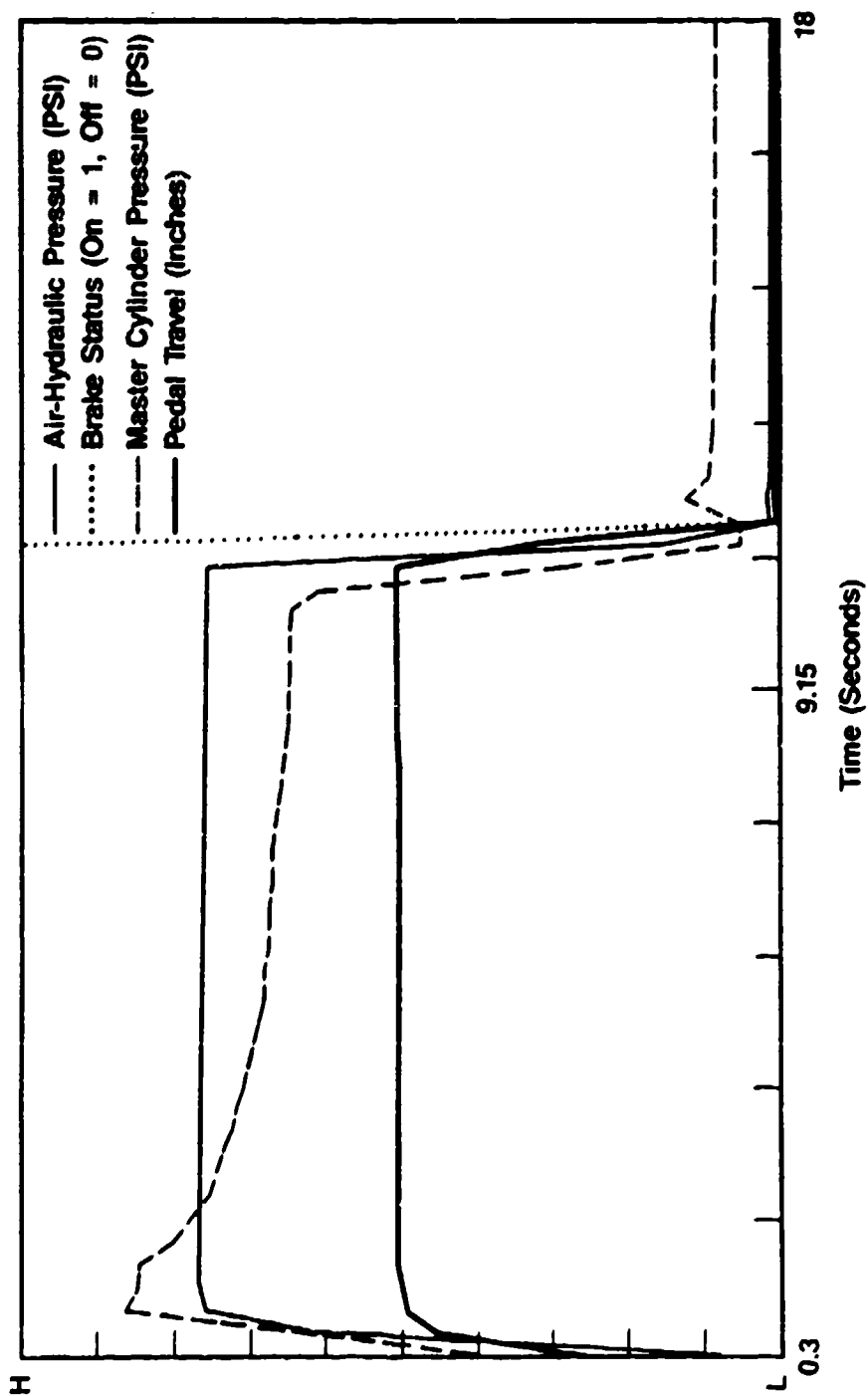


Figure 21. 5-Ton Polyglycol Truck Pedal Travel

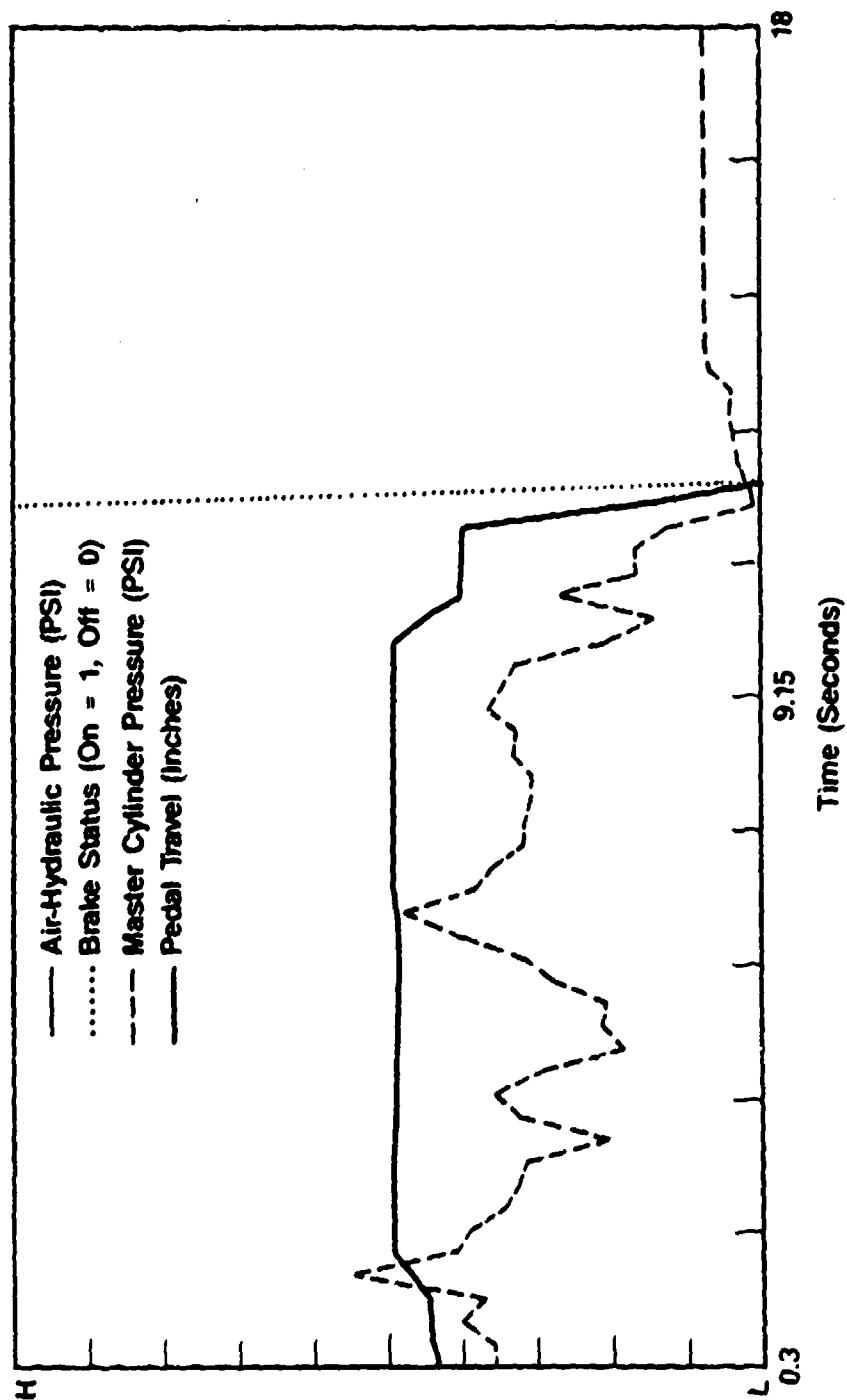


Figure 22. 5-Ton Silicone Truck (Uprun 6,100 feet)

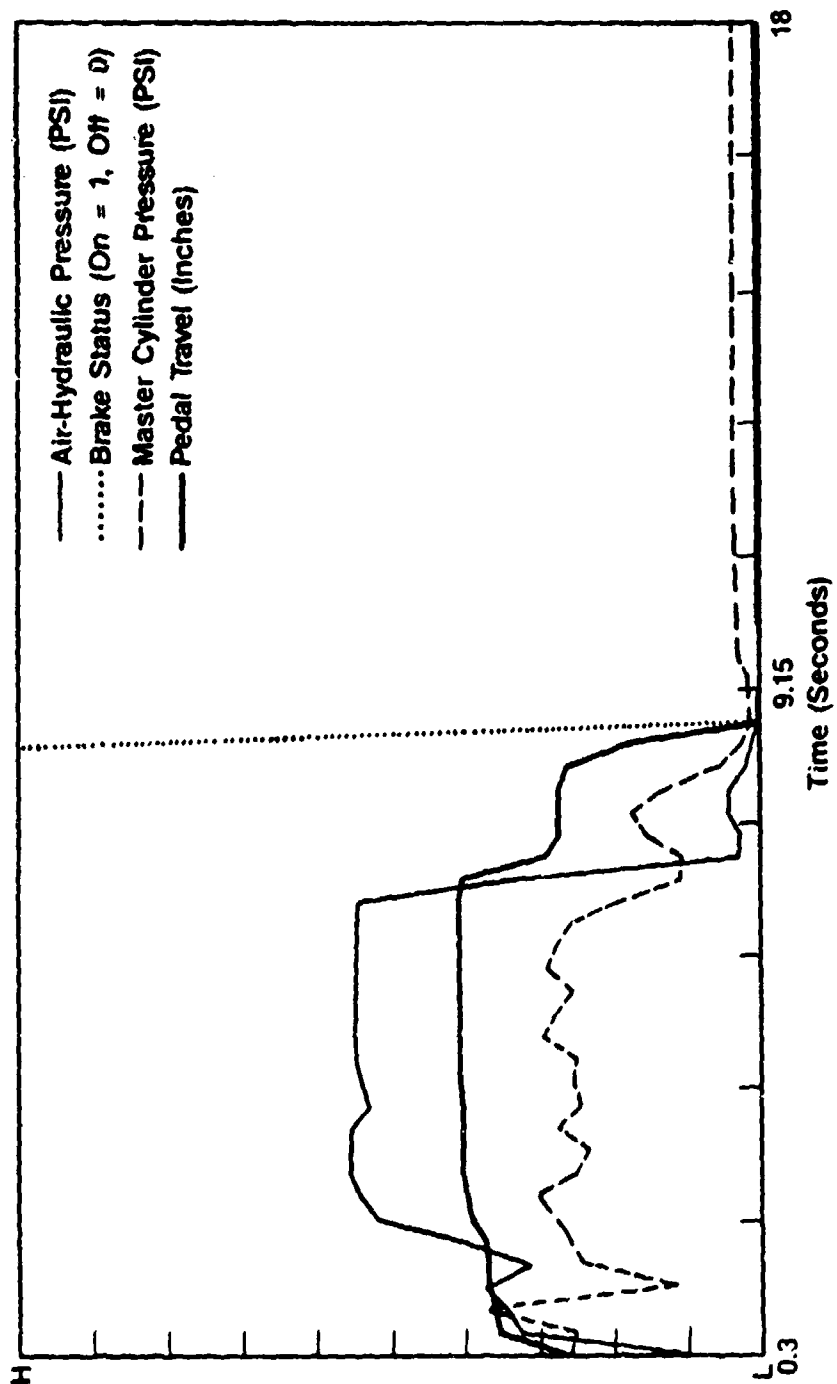


Figure 23. 5-Ton Polyglycol Truck (Uprun 6,100 feet)

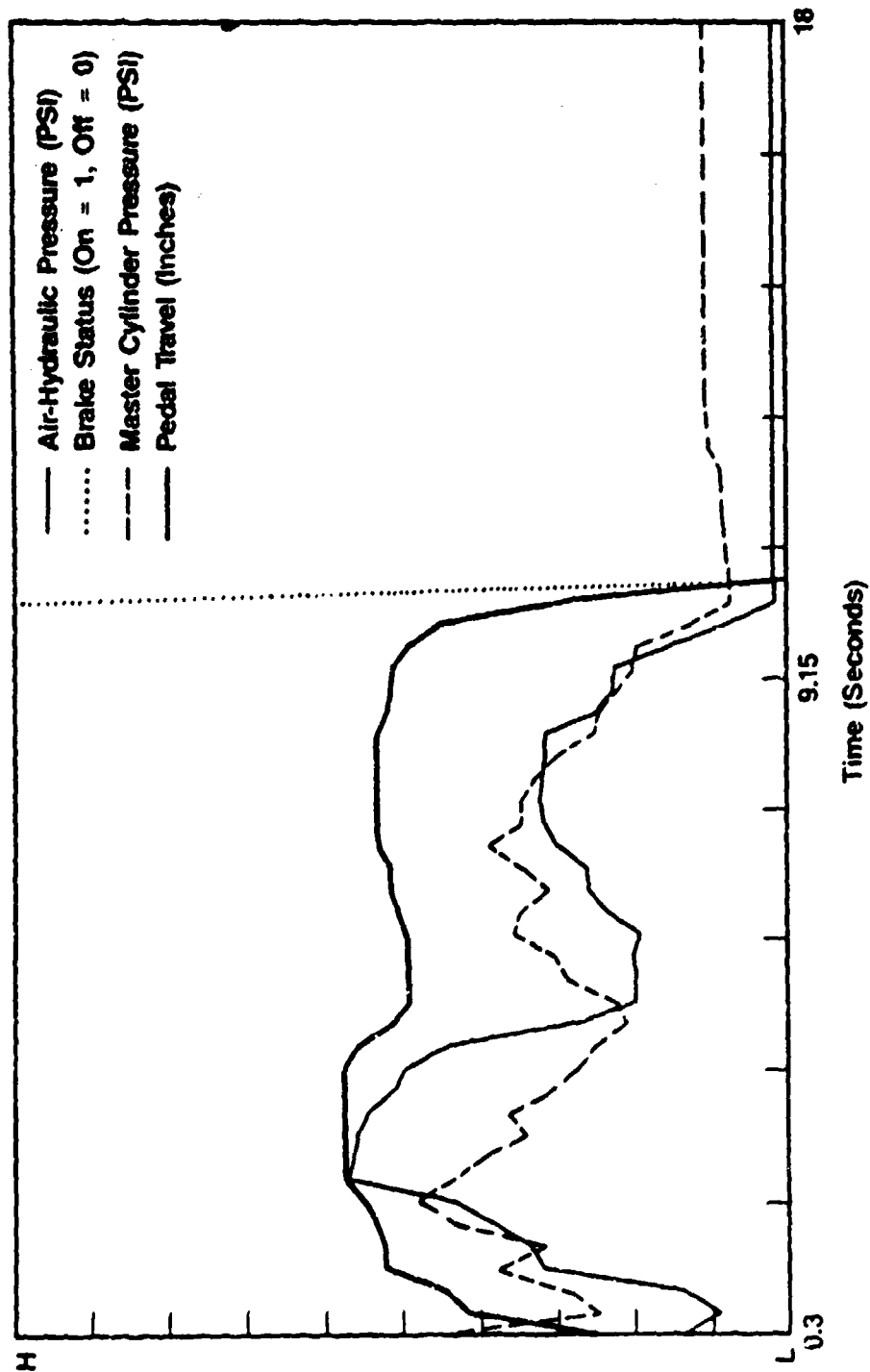


Figure 24. 5-Ton Silicone Truck (Uprun 8,100 feet)

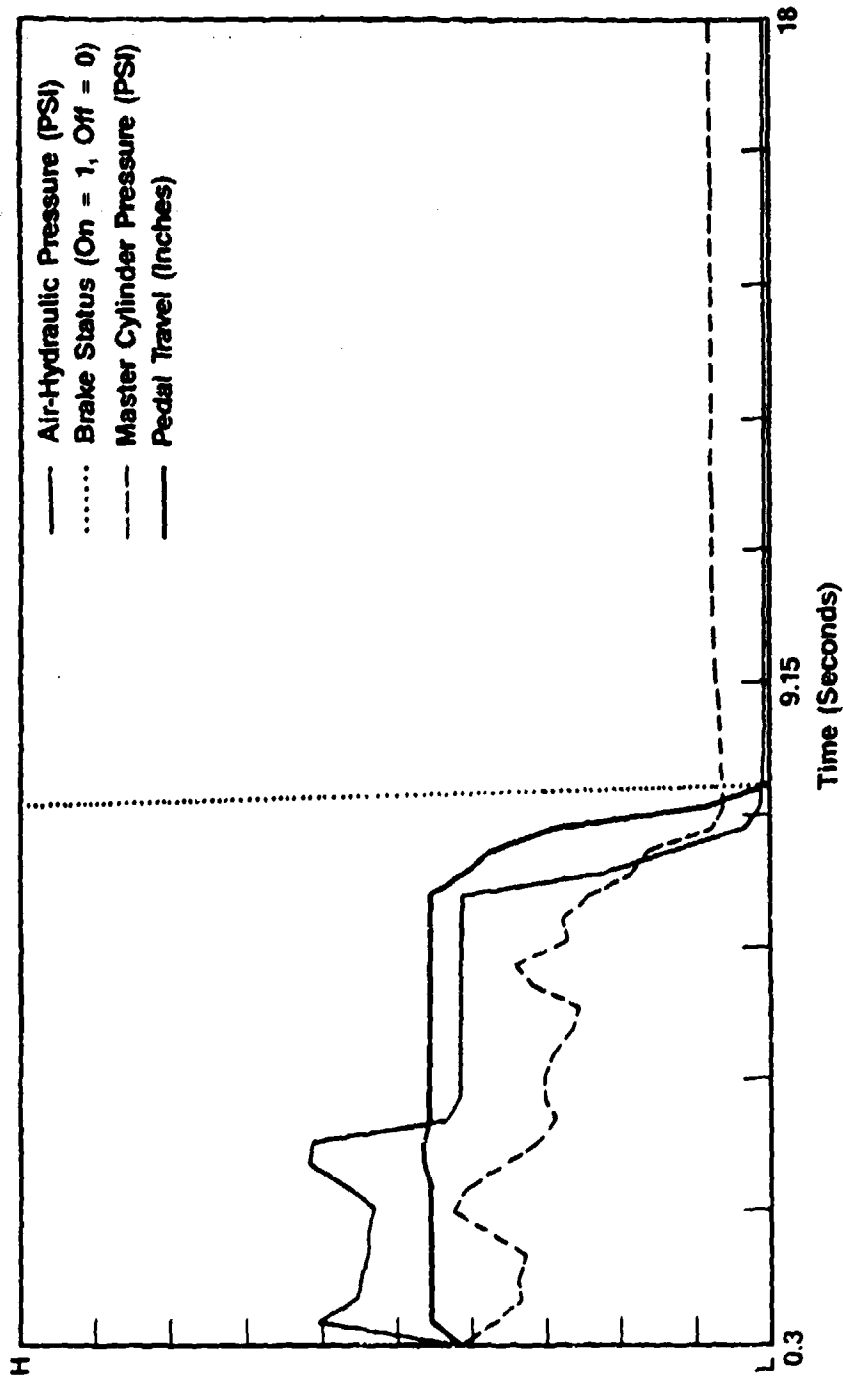


Figure 25. 5-Ton Polyglycol Truck (Uprun 8,100 feet)

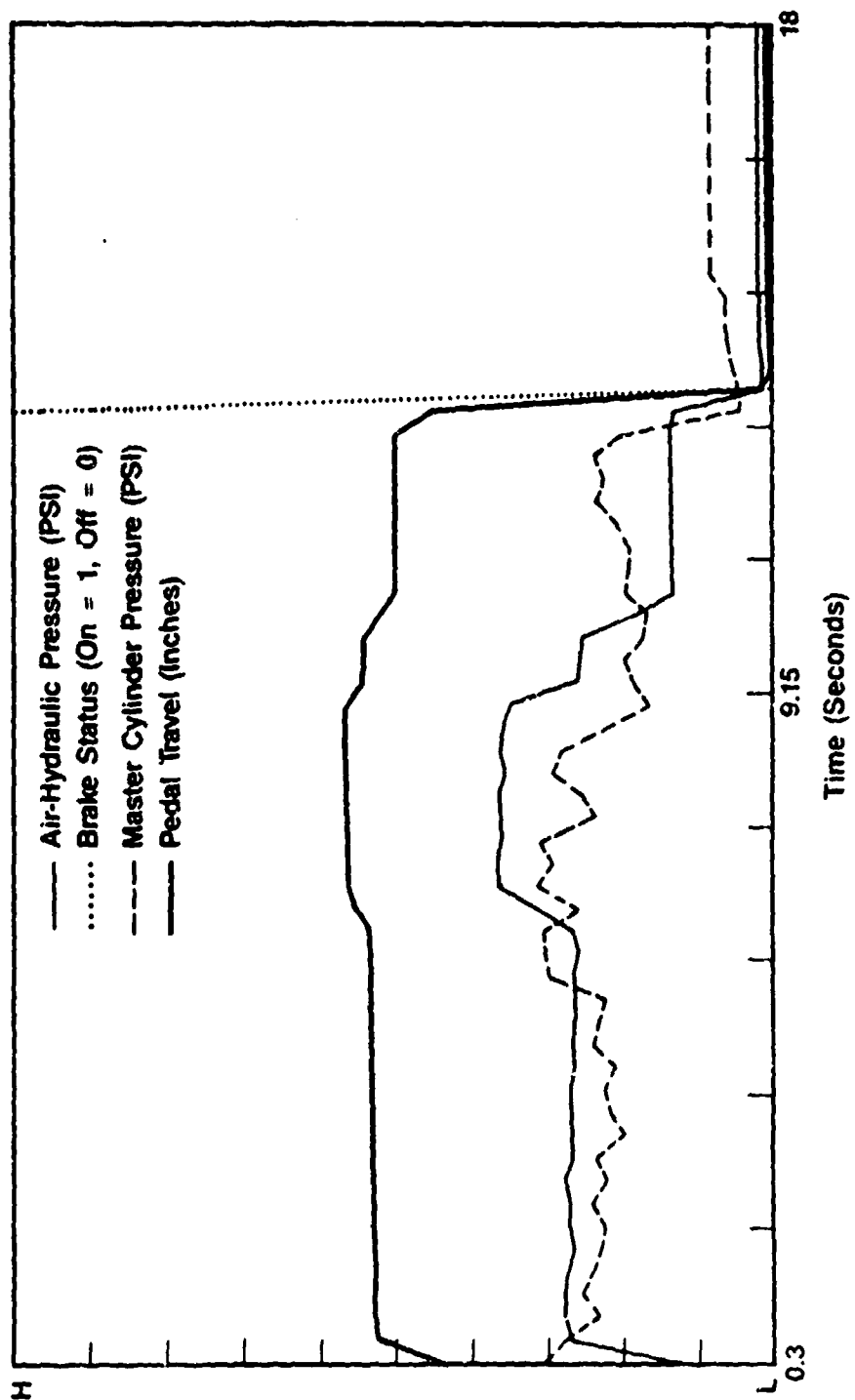


Figure 26. Silicone High Altitude Baseline

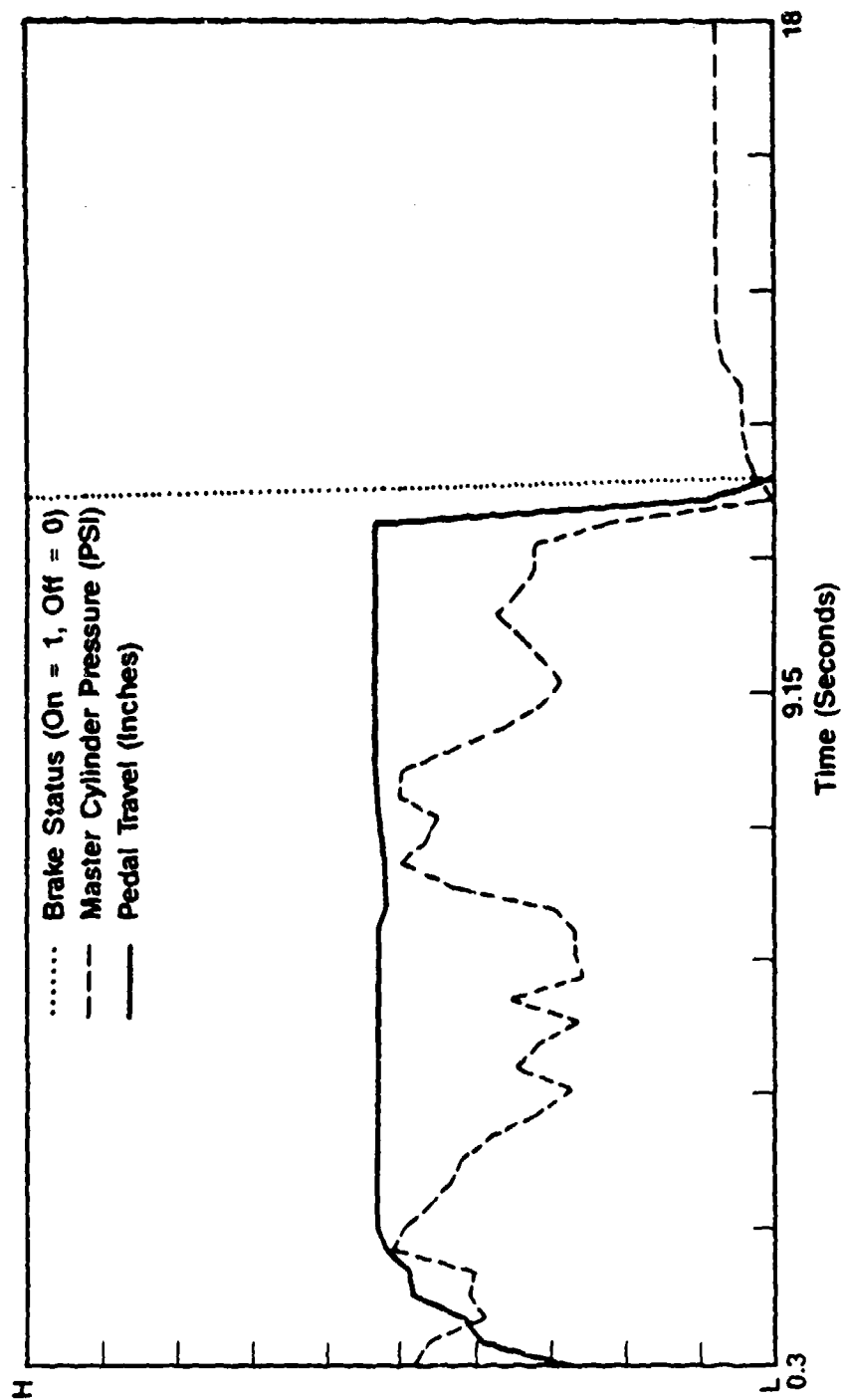


Figure 27. Silicone High Altitude Baseline With Vent

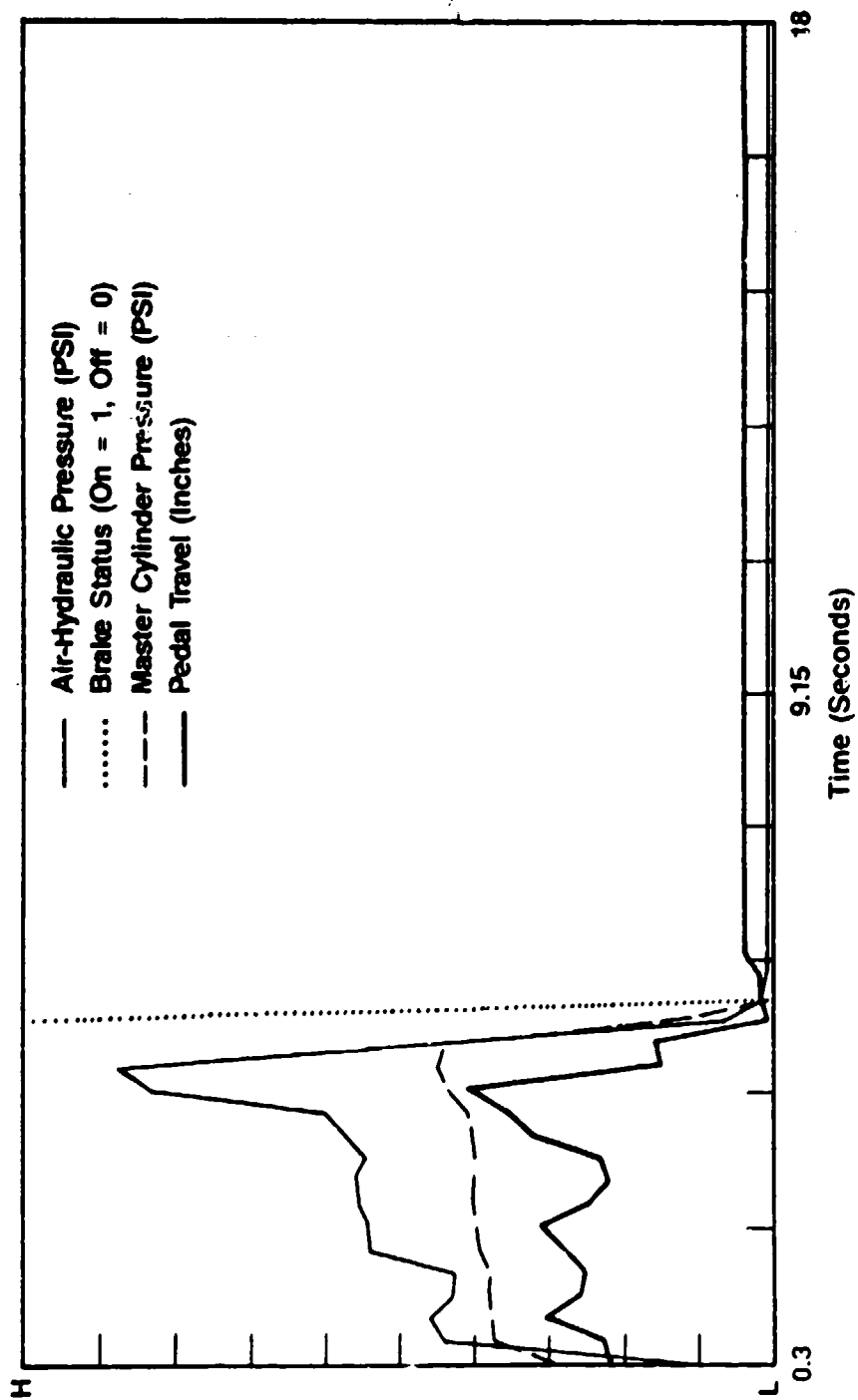


Figure 28. Polyglycol High Altitude Baseline

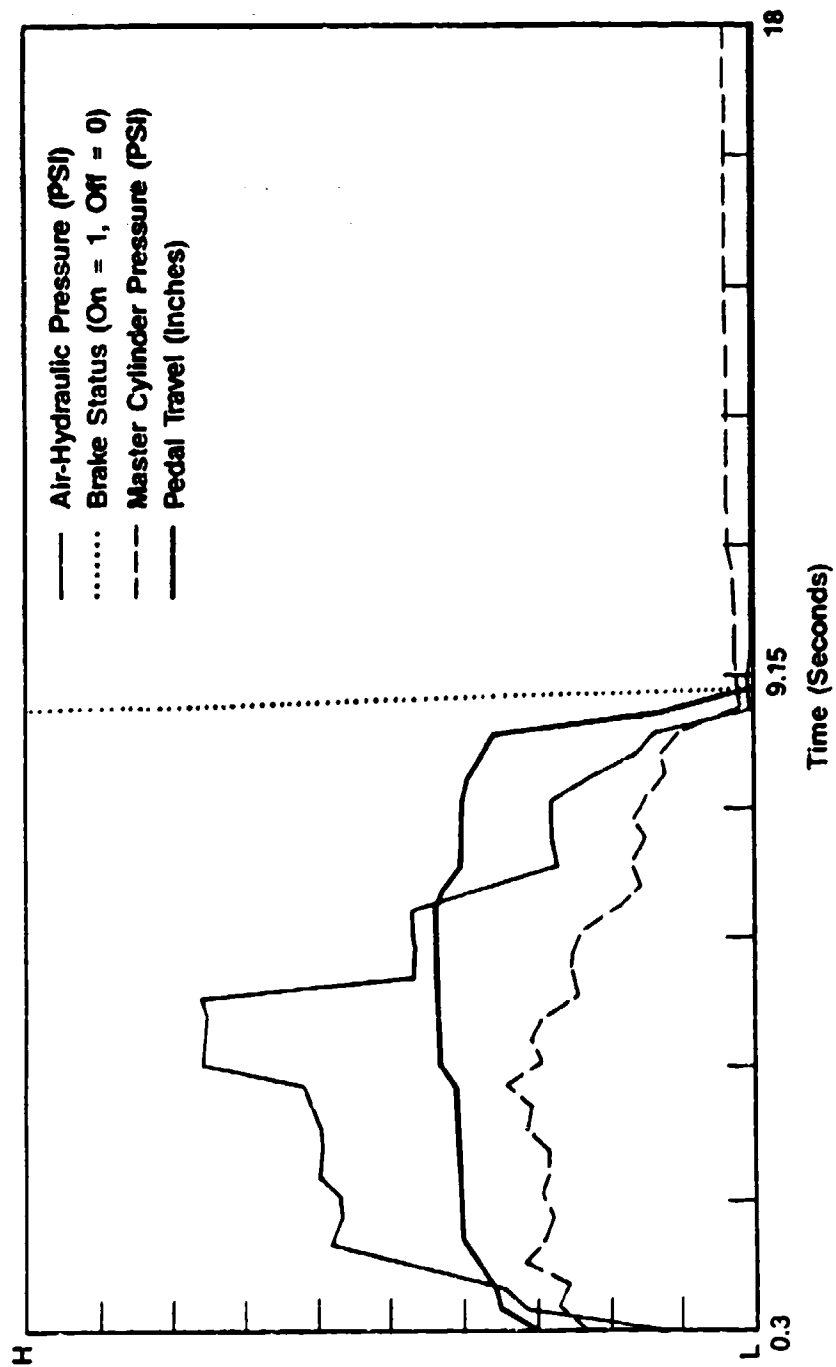


Figure 29. Polyglycol High Altitude Baseline With Vent

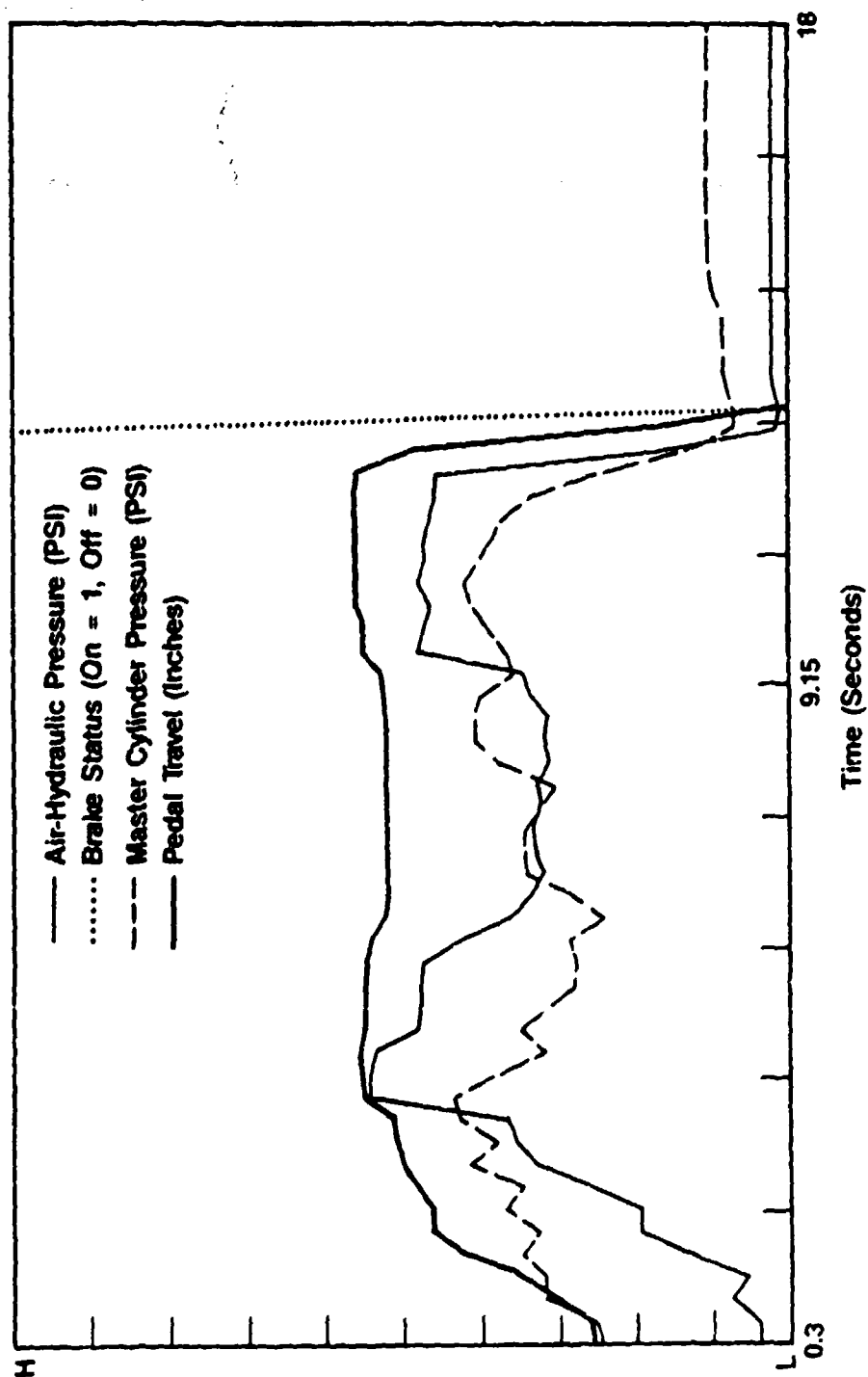


Figure 30. 5-Ton Silicone Truck (Downrun 8,100 feet)

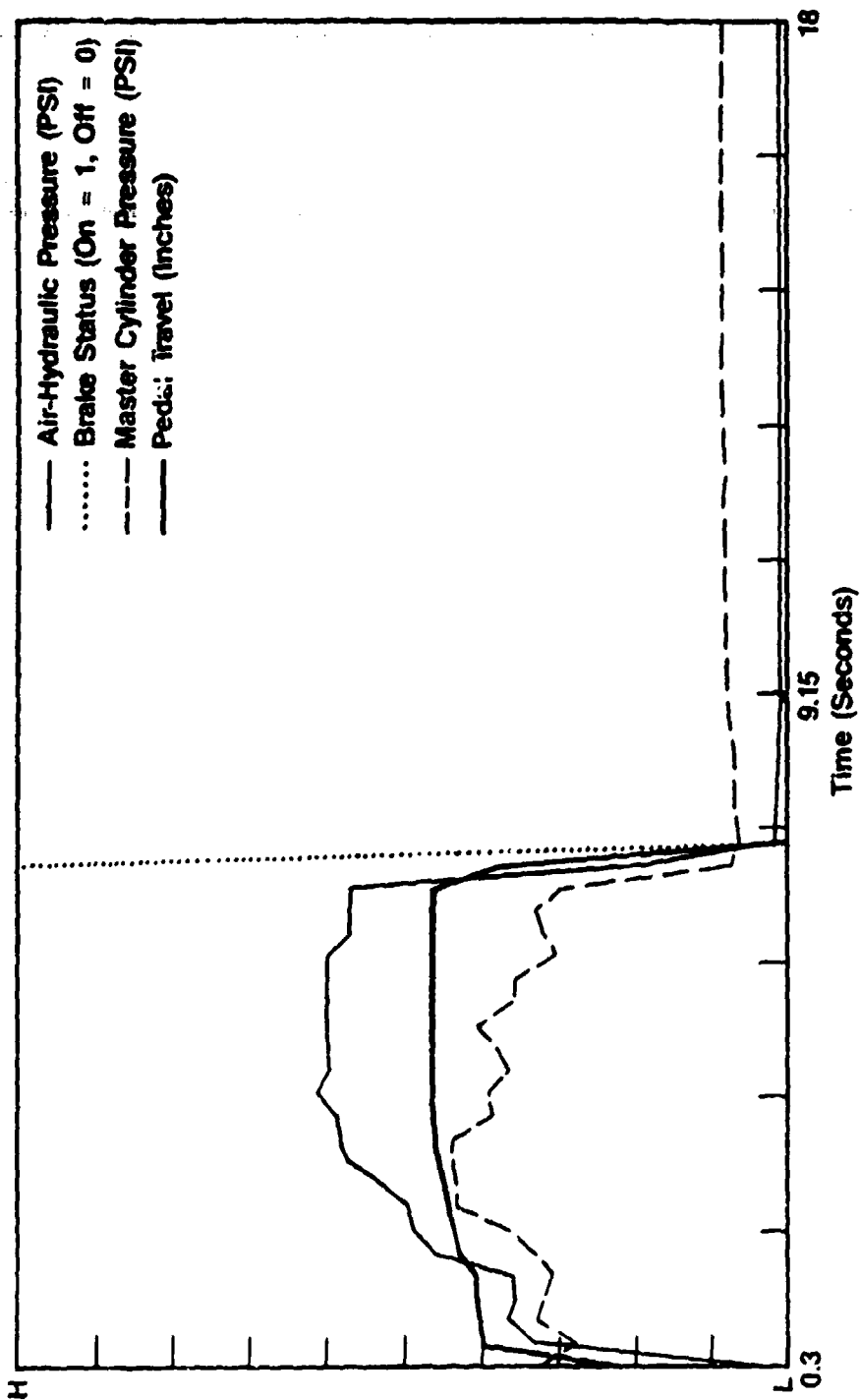


Figure 31. 5-Ton Polyglycol Truck (Downrun 8,100 feet)

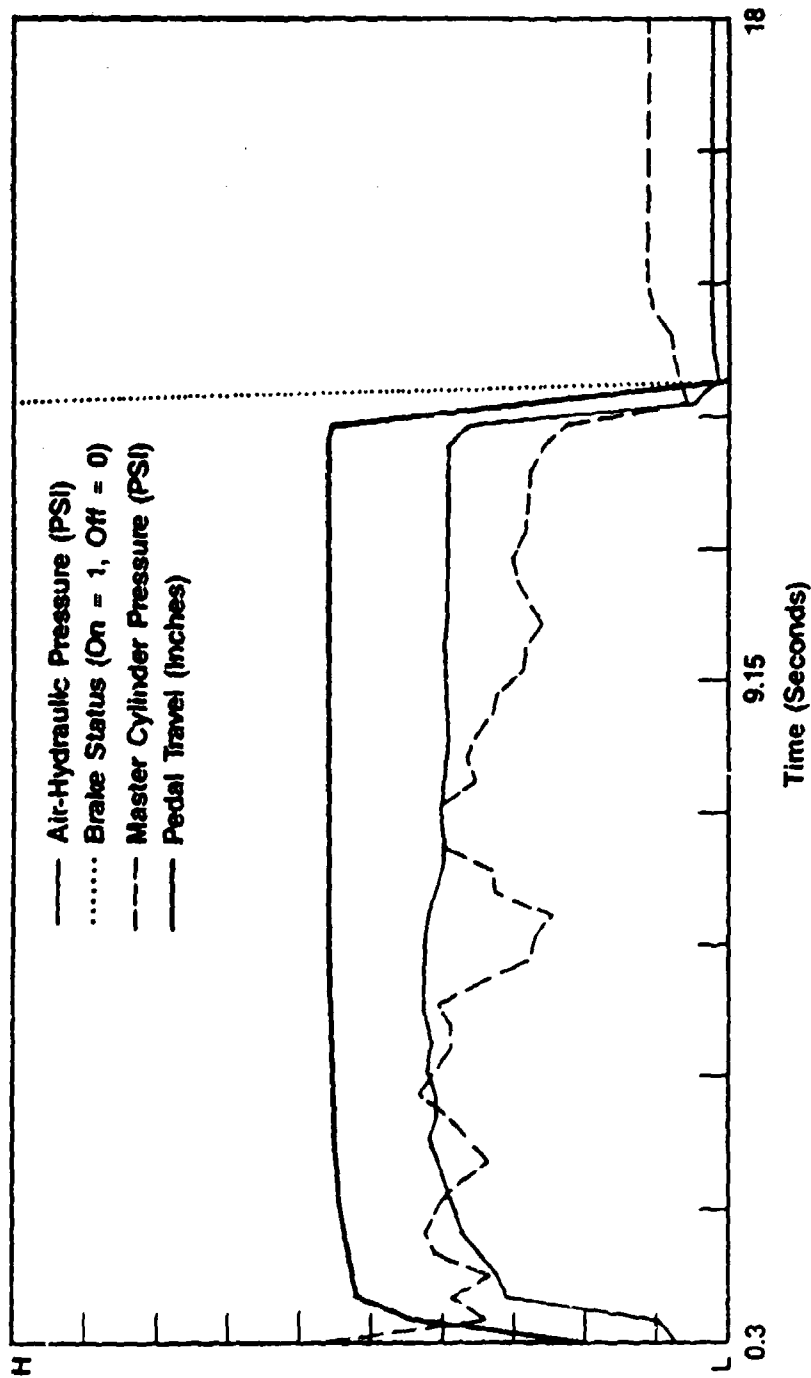


Figure 32. 5-Ton Silicone Truck (Downrun 5,300 feet)

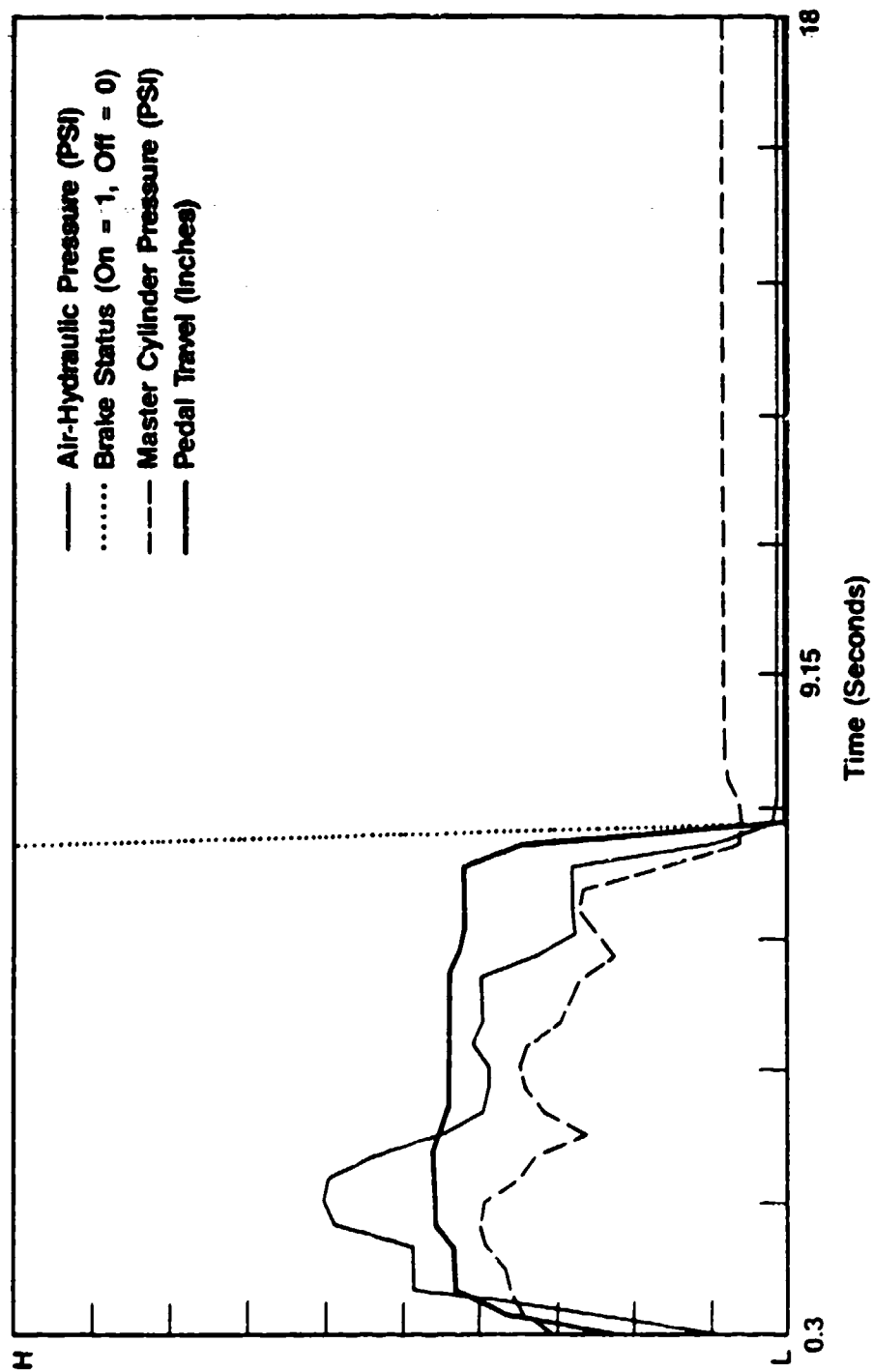


Figure 33. 5-Ton Polyglycol Truck (Downrun 5,300 feet)

Section V

Results and Analysis of Dissolved Air Bench Test

POLYGLYCOL TEST

The bench testing of the two brake fluids, polyglycol and silicone, was conducted as a supplement to the field testing in Utah. The bench test directly addressed the dissolved air issue in a quick, qualitative manner. By subjecting the fluid samples to decreased pressures in a controlled chamber, all other variables were eliminated and only the pressure factor was examined. In the case of the polyglycol fluid, the test failed to forcibly remove any detectable dissolved air from the fluid (results are summarized in Table 15). This was to be expected since the solubility of air in polyglycol is only 3 to 5% by volume. The polyglycol fluid evolved no detectable air when contained in a flask open to the atmosphere or when the flask was fitted with a one-way valve identical to the one on the 5-ton master cylinder vent cap.

Table 15. Polyglycol Bench Test

TEST PHASE	WITH VALVE			WITHOUT VALVE		
	Bubbles Present	Sample Weight	Change in Weight	Bubbles Present	Sample Weight	Change in Weight
I	None	49.4011	—	None	30.4996	—
II before	<5.5 psi	49.3968	.0043	<3.9 psi	30.4964	.0023
II after	0 psi	49.3952	.0016	0 psi	30.4952	0
III before	None	49.3891	.0061	None	30.4917	.0008
III after	None	49.3884	.0007	None	30.4916	.0006

SILICONE TEST

The BFS was also tested using an open flask and a flask outfitted with the one-way valve. As Table 16 indicates, dissolved air evolving from the brake fluid was detected. In Phase I (simulation of continuous increase in altitude), no air evolution was detected. In Phase II (simulation of decrease in altitude), however, air evolved at 5.5, 3.78, and 2.44 psi. These pressure values are equivalent to 24,000, 32,000, and 38,000 feet above sea level, respectively. While air does evolve from the fluid, it is still not a problem as far as operation of military vehicles is concerned. Although air can be forced from the fluid, the conditions under which this occurs are never encountered by the vehicles since they are not subjected to altitudes as high as even 24,000 feet. Further examination of the chart indicates that the one-way vent valve does not appreciably affect the evolution of air from silicone brake fluid.

Table 16. Silicone Bench Test

TEST PHASE	WITH VALVE			WITHOUT VALVE		
	Bubbles Present	Sample Weight	Change in Weight	Bubbles Present	Sample Weight	Change in Weight
I	None	49.5872	—	None	32.3809	—
II before	None	49.5796	.0031	None	32.3786	.0023
II after	None	49.5788	.0008	None	32.3786	0
III before	None	49.5771	.0017	None	32.3778	.0008
III after	None	49.5760	.0011	None	32.3772	.0006

Section VI

Conclusions and Recommendations

The thorough analysis of the data collected both during the field test and during the laboratory testing leads to the conclusion that BFS does in fact perform as intended. It must be stressed that the only function of the brake fluid in a hydraulic braking system is to transfer force that has been introduced to the system by the driver. In this respect, the BFS is successful despite its dissolved air content. The UTARNG has reported brake lock-up and loss of pedal as the problems associated with the 2 1/2- and 5-ton trucks equipped with air-over-hydraulic brakes. While the loss of pedal in the 5-ton truck was recorded and still cannot be explained completely, the problem of wheel lock-up cannot be fully addressed in this report as no lock-up occurred during testing and thus no data was recorded for analysis.

Although no actual lock-up data was recorded, it can be stated that the problems reported by UTARNG were not caused by BFS. The fluid serves only to act as a transfer medium and cannot hold pressure on its own. The only way the wheels can lock-up is for pressure to be exerted against the wheel cylinders. The natural tendency of BFS is to seek the lowest state of energy, i.e., least amount of fluid pressure. Pressure can only be applied to the wheel cylinders if pressure is applied to the fluid. This could occur if, for some reason, the fluid is prevented from returning to the master cylinder reservoir after the brake pedal is released and the return spring returns the pedal to its "up" position. Several misadjustments could account for this behavior. The return spring could be slightly out of adjustment, allowing the pedal to drop and thus partially apply the brakes even though the driver is not pressing the pedal. Another cause could be misadjustment of the pushrod in the master cylinder. If the rod is not positioned correctly, the opening in the reservoir could be partially blocked, preventing the return of fluid to the reservoir. This would cause a build-up of pressure in the fluid line, dragging wheels, and finally lock-up.

During the field test, the 2 1/2-ton truck did experience "brake failure" in that brake fade occurred. The loss of friction between the brake linings and brake drum will occur in any brake drum system when the brakes have been overstressed. This phenomenon is not restricted to air-over-hydraulic braking, or a specific type of brake fluid. Although the problem occurred in the silicone truck, the brake fade was brought on by the method employed by the driver rather than the brake fluid. If the driver were to repeat the same actions while driving the polyglycol truck, the same problem would most likely have occurred. This was substantiated during the additional testing on the 2 1/2-ton trucks at Camp Williams when the drivers were instructed to

purposely ride the brakes. When the brake drums achieved the target temperature, both trucks exhibited signs of brake fade.

In addition to the brake failure being attributed to brake fade, the dissolved air issue was resolved during this investigation. While air can be forced from BFS, the conditions necessary are so extreme that no military vehicle would encounter these conditions. It can be safely concluded that dissolved air in BFS does not prevent the brake system from performing as expected.

While not all questions have been answered completely, nor all unexplained brake failures resolved, the testing reported here rules out BFS as a possible cause. Further investigation of other aspects of the braking system may be necessary to completely explain the brake incidents that have been occurring.

References

1. Federal Specification VV-B-680, "Brake Fluid, Automotive," 20 July 1972; Military Specification MIL-H-13910, "Hydraulic Fluid, Polar Type, Automotive, All Weather," 3 February 1967; Military Specification MIL-P-46046, "Preservative Fluid, Automotive Brake System and Components," 26 August 1964.
2. Military Specification MIL-B-46176, "Brake Fluid, Silicone, Automotive, All Weather and Preservative," 27 March 1978.
3. J.H. Conley, R.A. Jamison, *Army Experience with Silicone Brake Fluids*, SAE Technical Paper Series, No. 780660, 1978.
4. "Proposed Addendum to the SAE J1705 Recommended Practice For Low Water Tolerant Brake Fluids."
5. Departments of the Army and the Air Force, *Principles of Automotive Vehicles*, 27 January 1956.

Appendix A

SAE Addendum: Air Solubility of BFS

PROPOSED ADDENDUM TO THE SAE J1705 RECOMMENDED PRACTICE FOR LOW WATER TOLERANT BRAKE FLUIDS

AIR SOLUBILITY

It has been reported that dimethyl polysiloxane fluid, which is a major component of silicone based low water tolerant type brake fluids (SAE J1705), can typically contain dissolved air at a level of $16\% \pm 3\%$ by volume at standard temperature and pressure. This compares with a typical level of $5\% \pm 2\%$ by volume of dissolved air for glycol ether based SAE J1703 type brake fluids. An increase in brake pedal travel may be experienced under severe operating conditions, especially at higher altitudes and high temperature conditions.

The term "dissolved air" (air absorbed from the atmosphere) should not be confused with the term "entrapped" or "free air" since their effects on brake system performance can be entirely different. Air that has been absorbed from the atmosphere does not result in an increase in fluid or system volume, whereas, entrapped air or free air does occupy system volume and can be easily compressed when force is applied to the system.

Appendix B

Excerpt from Automotive Handbook

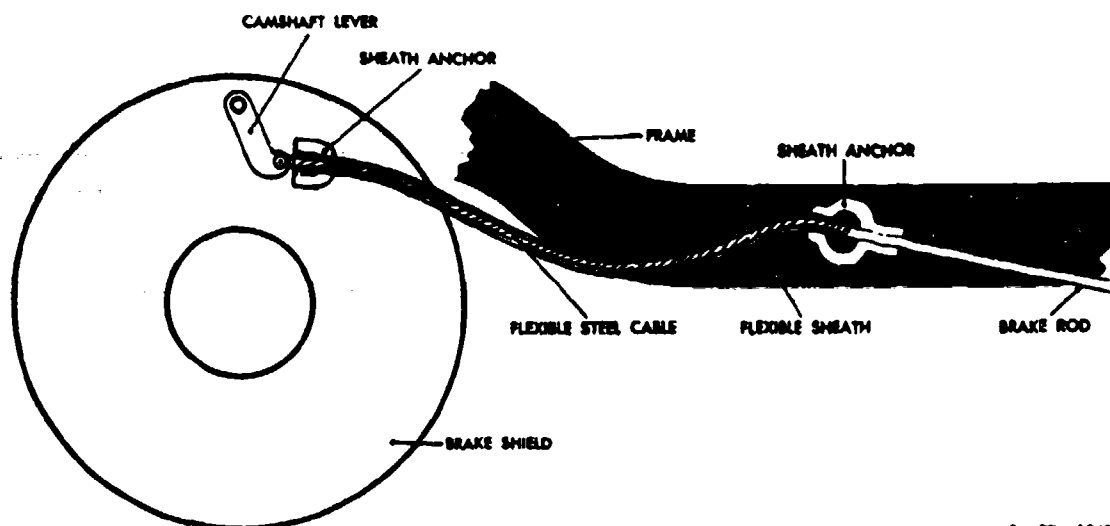


Figure 510. Brake-operating steel cable.

RA PD 184070

trolling the front wheels is the use of the brake rod attached to a camshaft, with a small universal joint above the steering knuckle pivot. A more popular and satisfactory method employs a flexible steel cable connecting the end of the brake rod to the brake camshaft lever (fig. 510). Because of the flexibility of the cable and its sheath, motion of the wheel does not affect tension on the cable. Flexible steel cables may also be used advantageously on the rear wheels, because of the vibration of the wheels when traveling over the

road. On some braking systems, the pressure on the wheel brakes is evenly distributed by various types of equalizers. Equalizers are designed to take up all the slack in the hookup to each brake so that all brakes will be applied at the same time. This prevents the possibility of too much pressure being applied to any one brake, which would lock that wheel and probably make the vehicle skid. One of the main reasons why the mechanical braking system has been supplanted is the difficulty of maintaining equal pressure on all brakes.

Section IV. HYDRAULIC SYSTEM

296. Principles

a. In hydraulic braking systems, the pressure applied at the brake pedal is transmitted to the brake mechanism by a liquid. To understand how pressure is transmitted by a hydraulic braking system, it is necessary to understand the fundamentals and principles of hydraulics. Hydraulics is the study of liquids in motion, or the pressure exerted by liquids conveyed in pipes or conduits.

b. One well-known hydraulic principle is that liquids cannot be compressed under ordinary pressures. This may be demonstrated by placing a weight on top of a piston fitted to a jar (fig. 511). The force of the weight does not change the level of the liquid, hence, it does not diminish the volume or compress the liquid.

c. Another well-known hydraulic principle is that force exerted at any point upon a confined liquid is distributed equally through the liquid in all directions. That is, if a total force of 20 pounds, including piston and weight, is placed upon liquid in a jar, and if the piston in the jar has an area of 5 square inches, the unit hydraulic pressure is increased by $20/5$, or 4 psi. This is illustrated in figure 512. A gage inserted at any point in the jar will indicate the same pressure of 4 psi, since the liquid transmits the pressure equally throughout the jar.

d. Use of these hydraulic principles may be illustrated by interconnecting two jars of the same diameter containing liquid (fig. 513). If a force is exerted on a piston in one jar (the left jar in fig. 513), a piston placed in the other jar will

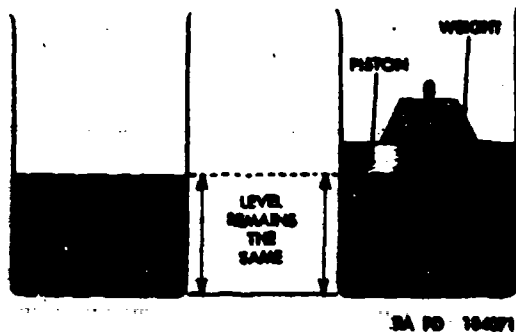


Figure 511. Noncompressibility of Liquids.

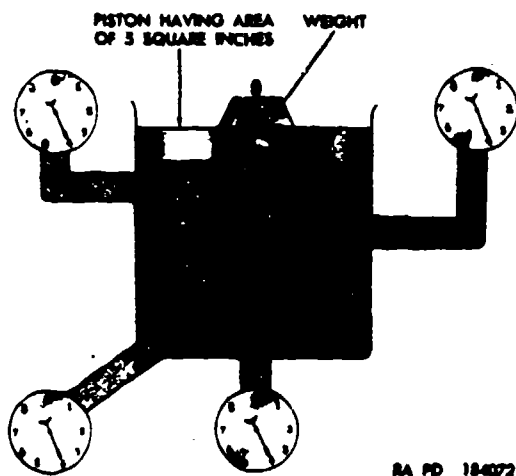


Figure 512. Equal distribution of force upon confined liquid.

receive the same amount of force, due to the transmission of pressure by the liquid. When the areas of the two pistons are equal, moving one piston produces identical movement in the other piston because the liquid is not compressible and therefore maintains the same volume.

e. By connecting one jar with another jar which has twice the diameter and therefore four times the area of the first jar (fig. 514), the results are somewhat different, although the same basic facts apply. When a force is exerted on the piston in the small jar, the piston in the large jar will receive four times as much force because the hydraulic pressure acts on four times the area. Since the liquid will always occupy the same volume, the large piston will move one-fourth as far as the

small piston. Thus, a mechanical advantage is obtained very similar to that obtained from a simple lever.

f. With four jars, all of the same diameter, connected to a central jar (fig. 515), an approximation of the action in 4-wheel brakes is obtained. A force exerted on the piston in the central jar will be transmitted to each of the other jars so that the piston in each will receive an identical force but will move only one-fourth as far as the central piston.

g. If the four jars have a larger diameter than the central jar, the total pressure on each of the four pistons is greater than that applied to the central one, and each of the four pistons moves less than one-fourth as far as the central piston. Hydraulic brake systems operate in such a manner.

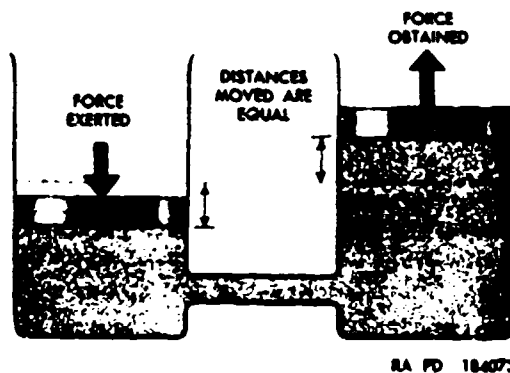


Figure 513. Distribution of forces in hydraulic system using same size pistons.

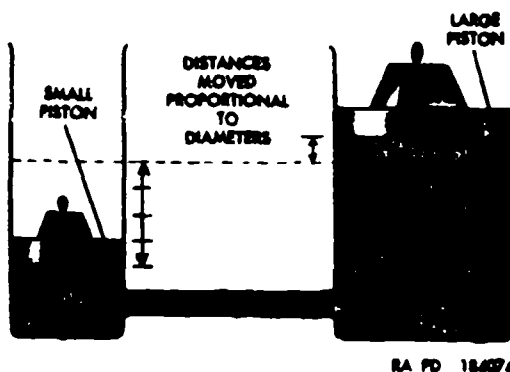


Figure 514. Distribution of forces in hydraulic system using different size pistons.

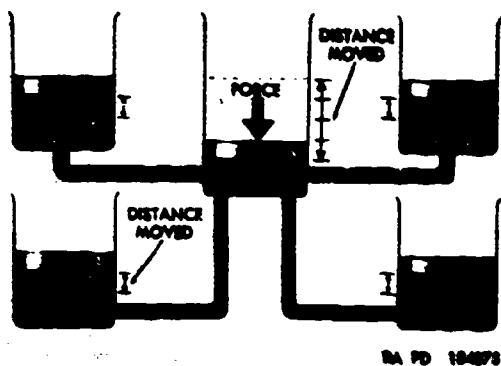


Figure 515. Four jars connected to a central jar.

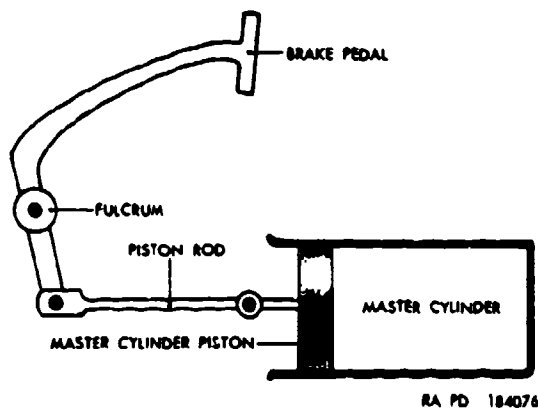


Figure 516. Foot pedal linkage to piston in master cylinder.

297. Operation

a. In a hydraulic brake system, the force is applied to a piston in a master cylinder that corresponds to the central jar (fig. 515). The brake pedal operates the piston by a linkage (fig. 516). Each wheel brake is provided with a cylinder fitted with opposed pistons connected to the brake shoes.

b. The brake pedal, when depressed, moves the piston within the master cylinder, forcing the brake liquid or fluid from the master cylinder through tubing and flexible hose into the four wheel cylinders. A diagram of a hydraulic brake system is shown in figure 517.

c. The brake fluid enters each of the wheel cylinders between opposed pistons, making the pistons move the brakeshoes outward against the brakedrum. As pressure on the pedal is increased,

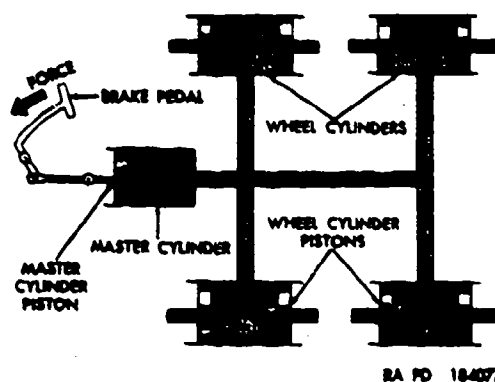


Figure 517. Diagram of hydraulic brake system.

greater hydraulic pressure is built up within the wheel cylinders and, consequently, greater force is exerted against the ends of the shoes.

d. When pressure on the pedal is released, retracting springs on the brakeshoes return the wheel cylinder pistons to their release position, forcing the brake fluid back through the flexible hose and tubing to the master cylinder.

298. Master Cylinder (fig. 518)

a. *General.* The master cylinder housing is an iron casting incorporating a large reservoir for the brake fluid. The cylinder is sometimes a unit by itself, in which case a supply tank is provided to feed the fluid to the master cylinder by gravity. The reservoir carries sufficient reserve fluid to insure proper operation of the braking system. It is filled through a hole at the top which is well sealed by a removable filler cap containing a vent. The cylinder is connected to the reservoir by two drilled ports, a large intake-port and a small bypass port.

b. *Piston.* The piston is a long, spool-like member with a rubber secondary cup seal at the outer end and a rubber primary cup which acts against the brake liquid just ahead of the inner end. This primary cup is kept against the end of the piston by a return spring. A steel stop disk, held in the outer end of the cylinder by a retainer spring, acts as a piston stop. A rubber boot covers the piston end of the master cylinder to prevent dust and other foreign matter from entering it. This boot is vented to prevent air from being compressed within it.

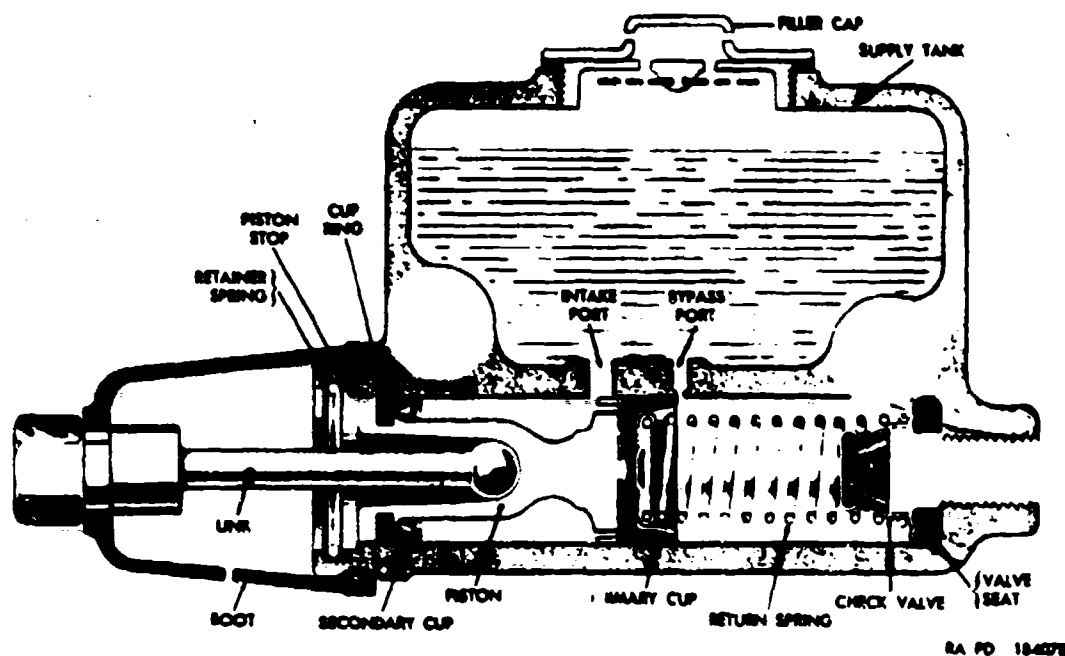


Figure 518. Master hydraulic brake cylinder—cross sectional view.

c. *Check Valve.* In the head of the master cylinder is a combination inlet and outlet check valve (fig. 518) held in place by the piston return spring. The check valve consists of a rubber valve cup incased in a steel valve case which seats on a rubber valve seat that fits in the end of the cylinder. In some designs, the check valve consists of a spring-operated outlet valve seated on a valve cage, rather than a rubber-cup outlet valve. The principle of operation is the same. The piston return spring normally holds the valve cage against the rubber valve seat to seal the brake fluid in the brake line.

299. Wheel Cylinder

a. *General.* The wheel cylinder (fig. 519) changes hydraulic pressure to the mechanical force that actually pushes the brakeshoes against the drums. The wheel cylinder housing is a casting mounted on the brake backing plate. Inside the cylinder are two pistons which are moved in opposite directions by hydraulic pressure and which, at the same time, push the shoes against the drum. The pistons or piston stems are connected directly to the shoes. Rubber piston cups fit tightly in the cylinder bore against each piston

to prevent the escape of brake liquid. There is a light spring between the cups to keep them in position against the pistons. The open ends of the cylinder are fitted with rubber boots to keep out foreign matter. Brake fluid enters the cylinder from the brake line connection between the pistons. At the top of the cylinder, between the pistons, is a bleeder hole through which air is

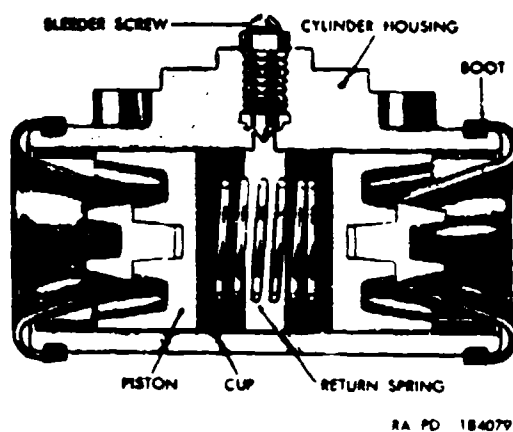


Figure 519. Wheel cylinder—cross sectional view.

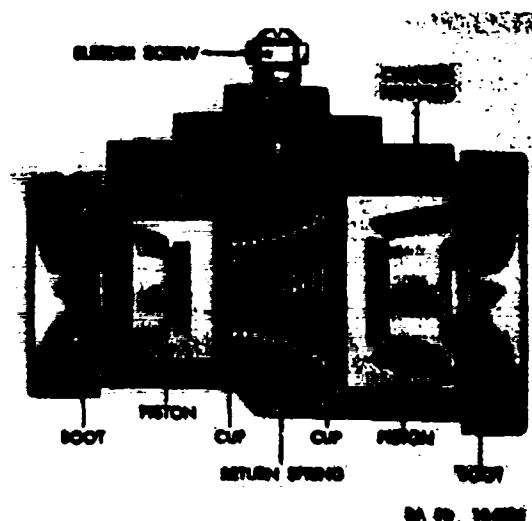


Figure 520. Stepped wheel cylinder—cross sectional view.

released when the system is filled with brake fluid.

b. *Variation in Arrangement.* A stepped wheel cylinder (fig. 520) is used to compensate for faster rate of wear on the front shoe than on the rear shoe, due to self-energizing action. By using a larger piston for the rear shoe, the shoe receives more pressure to offset the self-energizing action on the front shoe. This requires a stepped wheel cylinder with two bore sizes. If it is desired that both shoes be independently self-energizing, especially on front wheels, it is necessary to have two wheel cylinders, one for each shoe. Each cylinder has a single piston, and is mounted on the opposite side of the brake backing plate from the other cylinder. Such an arrangement is shown in figure 521.

300. Hill Holder

The hill holder provides greater ease of vehicular control on hills and in traffic. The device is connected to the clutch pedal and keeps the brakes applied as long as the clutch pedal is depressed when the car is on an upgrade, even after the brake pedal is released. The driver is then able to use his right foot for the accelerator pedal.

301. Handbrake and Dual Brake System

a. The handbrake in vehicles with a hydraulic system operates mechanically either on the transmission or transfer, or on the brakeshoes of the rear wheels. The transmission or transfer brake,

entirely independent of the hydraulic system, is of the type described in paragraph 289. When the handbrake operates on the wheels, it is usually linked to the same shoes that are operated by the hydraulic pistons. Toggle leverage (fig. 522) is used to apply the shoes. With this arrangement, the shoes are applied either hydraulically by the brake pedal, or mechanically by the hand lever.

b. In addition to the hydraulic system, some cars are fitted with a mechanical device designed to act on rear wheel brakes after the brake pedal has traveled a predetermined distance toward the toeboard. In normal operation, the braking action is entirely one of hydraulic force, the mechanical hookup working in connection with the hydraulic system. With the correct quantity of fluid in the lines and brakes properly set, the mechanical hookup is inactive; however, if the hydraulic system fails, the mechanical linkage acts as a safeguard. This mechanical hookup serves a further use as it may be connected to the hand brake lever for parking.

302. Brake Fluid

The liquid used for hydraulic braking is termed *brake fluid*. It is composed chiefly of equal parts

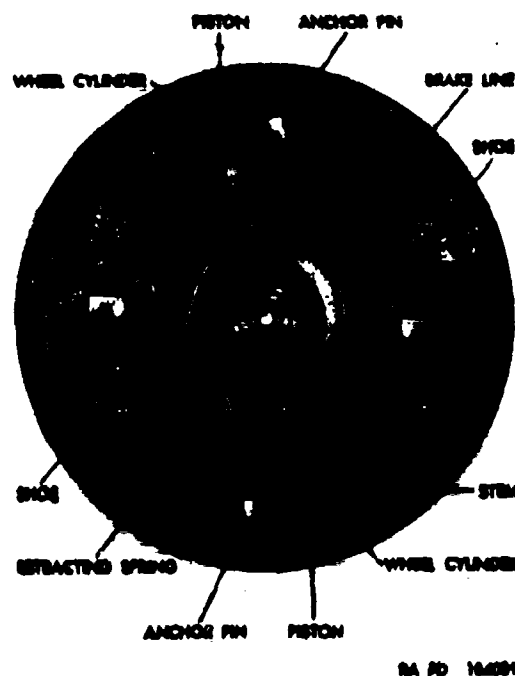


Figure 521. Single-piston two-cylinder mounting.

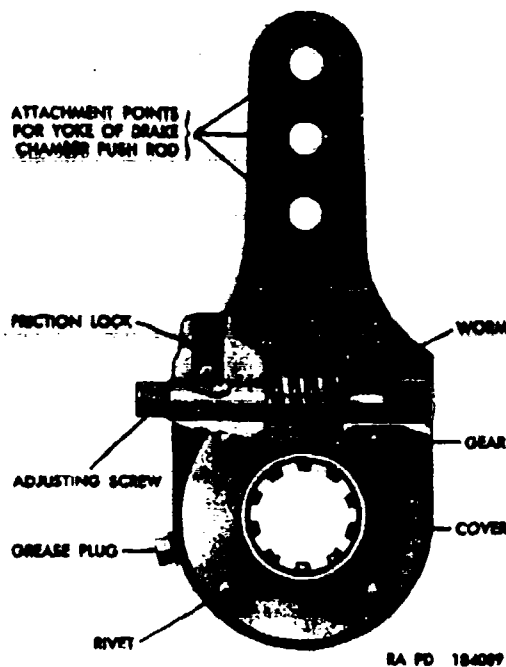


Figure 533. Black adjuster—partially cutaway view.

exhaust port closed. When the air pressure above the diaphragm is reduced by the operator releasing the brake pedal, the brake chamber air pressure lifts the diaphragm, opening the exhaust port and exhausting the compressed air pressure from the brake chamber.

g. Slack Adjusted (fig. 533). Slack adjusters function as adjustable levers and provide a means of adjusting the brakes to compensate for wear of linings. During brake operation, the entire slack adjuster rotates with the brake camshaft which is connected to the slack adjuster through the splined central hole. For brake adjustment, the worm moves the gear, changing the position of the lever arm with respect to the camshaft.

306. Air-Over-Hydraulic Brake System

a. General. The air-over-hydraulic brake system uses the principle of the hydraulic brake (para. 296 and 297) to operate the wheel brake cylinders and produce braking action. However, the hydraulic pressure for the wheel brake cylinders is not supplied from the master cylinder. Instead, there are two circuits. The first leads from the

air-hydraulic cylinder, and admits air pressure which actuates this cylinder by moving an air piston that is connected to a hydraulic piston. The hydraulic piston then applies the hydraulic pressure that produces the braking action. The air is admitted by the action of valves controlled by the hydraulic pressure from the master cylinder.

b. Construction. The air-over-hydraulic brake system is shown in figure 534. Air pressure is supplied by a compressor and stored in reservoirs as with the air brake system (para. 304 and 305). The master cylinder is similar to the master cylinders used in hydraulic brakes (par. 298). Also, the wheel brake cylinders and wheel brake construction are very similar to that used in hydraulic brakes. The essential difference between the straight hydraulic brake system and the air-over-hydraulic brake system lies in the air-hydraulic cylinder. This cylinder consists of three essentials: a large-diameter air piston; a small-diameter hydraulic piston in tandem with it, both on the same rod; and a set of valves controlled by hydraulic pressure from the master cylinder for admitting air into the air-cylinder section of the air-hydraulic cylinder.

c. Operation.

- (1) The air-hydraulic cylinder (fig. 535) embodies an air cylinder and a hydraulic cylinder in tandem, each fitted with a piston with a common piston rod between. The air piston is of greater diameter than the hydraulic piston. This difference in areas of the two pistons gives a resultant hydraulic pressure much greater than the air pressure admitted to air cylinder. Automatic valves, actuated by fluid pressure from master cylinder, control the air admitted to air cylinder. Thus the fluid pressure in brake lines is always in a direct ratio to foot pressure on brake pedal. An air line from air-hydraulic cylinder leads to a trailer coupling at rear of vehicle.
- (2) Valve movement varies with the amount of brake pedal pressure, as mentioned in paragraph 305c. When heavy brake pedal pressure is applied by the driver for hard braking, the hydraulic pressure in the master cylinder (which operates the valves) causes greater valve movement, and therefore the valves admit more air

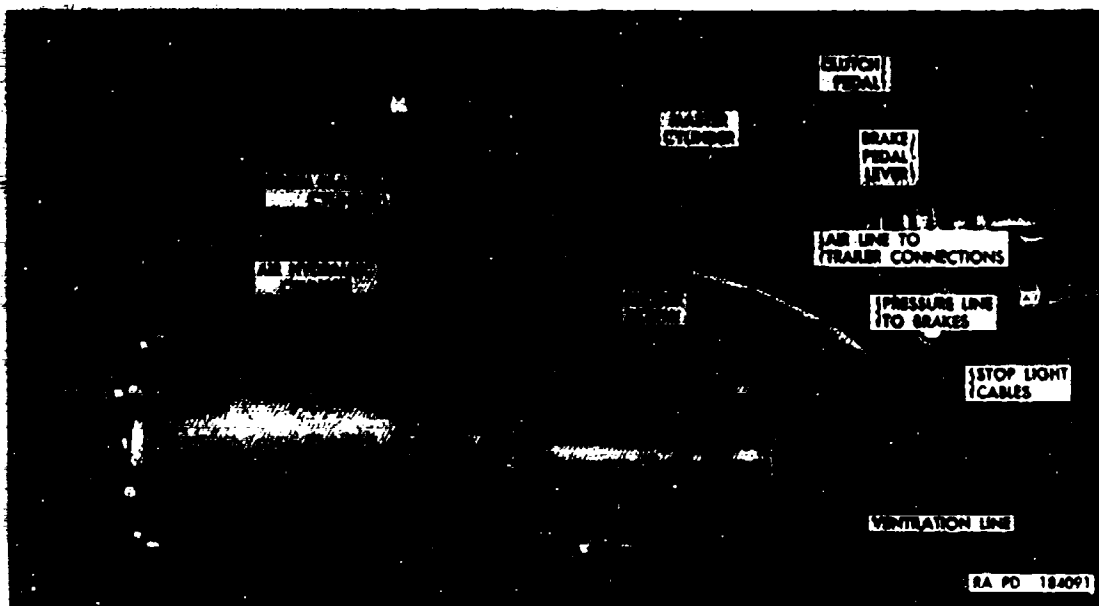


Figure 138. Air-hydraulic cylinder installed in vehicle.

pressure into the air-hydraulic cylinder. This higher air pressure causes a stronger braking action. With only a light brake pedal pressure, the valves admit less air pressure into the air-hydraulic cylinder and the braking action is lighter.

307. Vacuum Brake System

a. Principle.

- (1) In order to understand the principle on which the vacuum brake system operates, it is necessary to know what a vacuum is and how it can be used. For practical purposes, a vacuum may be defined as a space from which air or gas has been partially exhausted.
- (2) Air, like all matter, has weight. Since air extends upward from sea level for several hundred miles, the weight of this air exerts a pressure (termed *atmospheric pressure*) at sea level of 14.7 psi. This pressure is equally distributed in all directions upon all objects of the earth's surface. See paragraph 10c for a discussion of atmospheric pressure and vacuum.
- (3) Atmospheric pressure may be used to operate brakes by the creation of a vacuum. Since a vacuum is created by removing air, the pressure within a vacuum is less than that of the atmosphere. A perfect vacuum from which all matter has been removed has no weight or pressure. A perfect vacuum is never obtainable, although it can be closely approached. Hence, the full force of 14.7 psi atmospheric pressure can never be utilized. If air in a container has been pumped out, or evacuated, until only 5 psi pressure remains, the psi differential existing between vacuum pressure and atmospheric pressure may be used to perform work.
- (4) Vacuum is created in the intake manifold of an internal combustion engine by the pumping action of the pistons. When the vehicle is coasting in high gear with the carburetor throttle fully closed, very little air is admitted into the intake manifold, so that the pumping action of the pistons reduces the pressure to about 5 psi in the manifold. The driver's foot is taken off the accelerator pedal when he applies the brakes so that the difference between the vacuum pressure and atmospheric pressure (about 10 psi) is available to operate the brakes.

Appendix C

BFS Performance Test Plan

SILICONE BRAKE FLUID PERFORMANCE DATA ACQUISITION AT HIGH ALTITUDES

INTRODUCTION

- Purpose:** The purpose of this experiment is to monitor the physical properties characteristic of an air-hydraulic brake system to determine if silicone brake fluid performs satisfactorily under high altitude conditions.
- Background:** Brake failures reported by the Utah National Guard in the January 9, 1989 memo have been attributed to the dissolution of air in the silicone brake fluid due to the decreasing pressures experienced when traveling to and from high altitudes. According to the addendum to the SAE J1705 Recommended Practice for Low Water Tolerant Brake Fluids, testing has revealed that silicone brake fluids can contain up to $16\% \pm 3\%$ by volume of dissolved air at standard temperature and pressure. It is also known that conventional polyglycol brake fluids contain only 3% to 5% dissolved air.
- The Utah National Guard maintains that upon traveling to and from higher altitudes, the 2 1/2 and 5 ton trucks equipped with air-hydraulic braking experience problems ranging from brake lock-up to complete brake loss due most likely to the behavior of silicone brake fluid. These problems reportedly did not occur when the braking system utilized conventional type polyglycol fluid. This test is designed to collect operating data concerning the physical properties characteristic of the brake system for both silicone brake fluid and polyglycol fluid.
- Scope:** This test will attempt to chronicle the behavior of both silicone and polyglycol brake fluids when used in identical vehicles actually operating in increased altitude conditions. It is proposed that two 5 ton and two 2 1/2 ton trucks be outfitted with instrumented brake systems. One truck in each set will contain the silicone brake fluid while the other truck will contain the conventional polyglycol fluid. Trucks will be driven over a predetermined course and brake system data will be recorded.
- Objective:** The primary objective of this experiment is to monitor how the brakes on 2 1/2 and 5 ton trucks perform given different brake fluids and increasing/decreasing altitude conditions. Brake line pressures, wheel cylinder and master cylinder temperatures, as well as brake pedal travel will be measured. Monitoring the pressure will indicate if a sufficient amount of air is entering the brake system to cause failure. Monitoring the wheel cylinder temperature will indicate the possibility of temperatures high enough to cause the fluid to vaporize.

PROJECT CONCEPT AND PROCEDURES

Concept:

This field test is intended to characterize the performance of silicone and conventional glycol-type brake fluid under actual environmental conditions encountered at high altitudes. All trucks will be operated through a specified course which will provide altitude variations. Data will be collected during actual braking action then down-loaded to the lap top PC for analysis.

Procedure:

APPARATUS ASSEMBLY (see figure 1)... The instrumentation will be installed on site and will consist of (for each truck) a linear resistor to monitor pedal travel, four copper/constantan thermocouples, one 0-500 psi pressure transducer, one 0-5000 psi pressure transducer. A Campbell Scientific 21X Data Logger and lap top personal computer will be installed just prior to testing.

The instrumented braking system will consist of a master cylinder with a thermocouple installed through the vent valve to allow direct fluid temperature to be monitored. Thermocouples will also be mounted on the front and rear wheel cylinders to measure the heat generated at the wheel site due to the braking action of the truck. Pressure transducers will be installed in the brake lines between the master cylinder and the air-hydraulic cylinder, and between the air-hydraulic cylinder and the wheel cylinder. The data from these measuring devices will be stored in a data logger and then down loaded to a lap top personal computer for data reduction and manipulation. Prior to testing at the Utah site, the instrumentation will be installed on a 5 ton truck for a trial run at Ft. Belvoir to insure that the system is completely de-bugged and operational. After the system has been successfully tested, the wheel cylinder bleed valve will be opened to remove 5 cc of the silicone fluid and then 5 cc of air will be injected into the wheel cylinder. Then truck will be operated and data recorded to obtain a physical properties profile of a brake system failure due to air being in the system. This will provide a basis of comparison for evaluating the data obtained at the Utah site.

TEST METHOD.....Once instrumented, each truck will be run over a specified course that will exhibit all altitude conditions encountered during normal vehicle operation. The course will be determined by BRDEC personnel with the assistance of UTANG. The course will be such that the truck will travel at 35 mph continuously from 4,000 feet to 11,000 feet above sea level and then back down. Before testing, base line data will be collected at 4,000 feet to provide operating temperatures and pressures of the system. This data in turn will establish stabilization parameters for the tests. The brakes will be applied a sufficient number of times to stabilize brake system temperatures and pressures.

After stabilization, testing will occur in four phases. In the first phase, the truck will run the course with brake application (the truck will come to a complete stop) occurring every 1000 feet of altitude until 11,000 feet is reached. The truck will then be allowed to stabilize at 11,000. In the second phase, the truck will be run at a constant altitude (11,000 ft) braking at least 7 times from 35 mph to a complete stop. Again, the truck will be allowed to stabilize before initiating phase three. In the third phase the truck will descend from 11,000 feet to 4,000 braking every 1,000 feet as before.

The fourth and final phase will consist of a series of step tests. Step testing acts as an accelerated simulation of the behavior exhibited by the trucks when stored at one altitude then moved to another. The trucks will travel to 8,000 feet and be allowed to stabilize. At the end of this time, the trucks will be operated over a course that remains at this altitude and data recorded in the same manner as previously prescribed (braking at least 7 times). The trucks will then climb to the final altitude of 11,000 feet and again be allowed to stabilize before commencing braking activity and data acquisition. The same procedure will be repeated for the decent of the truck to 8,000 feet and again at 4,000 feet.

This test will also investigate the possibility that the configuration of the 1-way valve in the vent caps of master cylinders installed on the 5T trucks (for purposes of fording) is responsible for brake failures. The 5T trucks will be run through the four test phases first with a T-fitting that accomodates the 1-way valve and a thermocouple and then with the old two-way valve with the thermocouple installed through the cap. A comparison of the data collected for the 1-way valve operation and the 2-way valve operation will indicate the effect on brake system operation due to the valve configuration.

Data Reduction:

Data will be transferred from the data logger to the PC as needed during all three testing phases. Upon completion of testing on each truck, the accumulated data will be reviewed to determine if testing modifications are required. The data logger is configured to take samples every 2 seconds for a period of two minutes after the brakes have been activated. This will provide a near continuous measurement of pressure and temperature. Plots of temperature, pressure, pedal travel, altitude, and time will be generated to best present brake system performance.

MANAGEMENT AND RESPONSIBILITIES

Relationships:

The Utah Army National Guard (UTANG) has requested assistance from TACOM, Tank Automotive Command, and Belvoir Research, Development, and Engineering Center (BRDEC) to isolate the factors responsible for brake failures occurring in 2 1/2 and 5 ton trucks.

Points of Contact:

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Responsibilities:

UTANG will provide materiel, operators, and maintenance support for BRDEC personnel.

TACOM will support investigation of silicone brake fluid performance by BRDEC personnel.

BRDEC will conduct testing to collect data on the performance of silicone brake fluid.

UTAH TRAVEL & TEST ITINERARY

DATE	ACTIVITY
16 July	Check into Red Lion in Salt Lake City
17 July	Introductions to UTANG personnel and determine actual braking course by marking with stakes and flags
18 July	Install new brake system parts
19 July	Install new brake system parts and instrumentation
20 July	Complete instrumentation of truck
21 July	Begin actual data collection on 5T trucks and reduce data (1-way valve)
22 July	Continue testing and data reduction for 5T trucks (1-way valve)
23 July	Continue testing and data reduction for 5T trucks (1-way valve)
24 July	Convert 1-way valve to 2-way valve and begin data collection on 5T
25 July	Continue testing and data reduction for 5T trucks (2-way valve)
26 July	Continue testing and data reduction for 5T trucks (2-way valve)
27 July	Begin actual testing on 2 1/2T trucks and reduce data
28 July	Continue data collection and reduction for 2 1/2T trucks
29 July	Continue data collection and reduction for 2 1/2T trucks
30 July	Complete on-site data manipulation and wrap up testing
31 July	Return to BRDEC
1-14 August	Evaluation of findings and preparation of final report

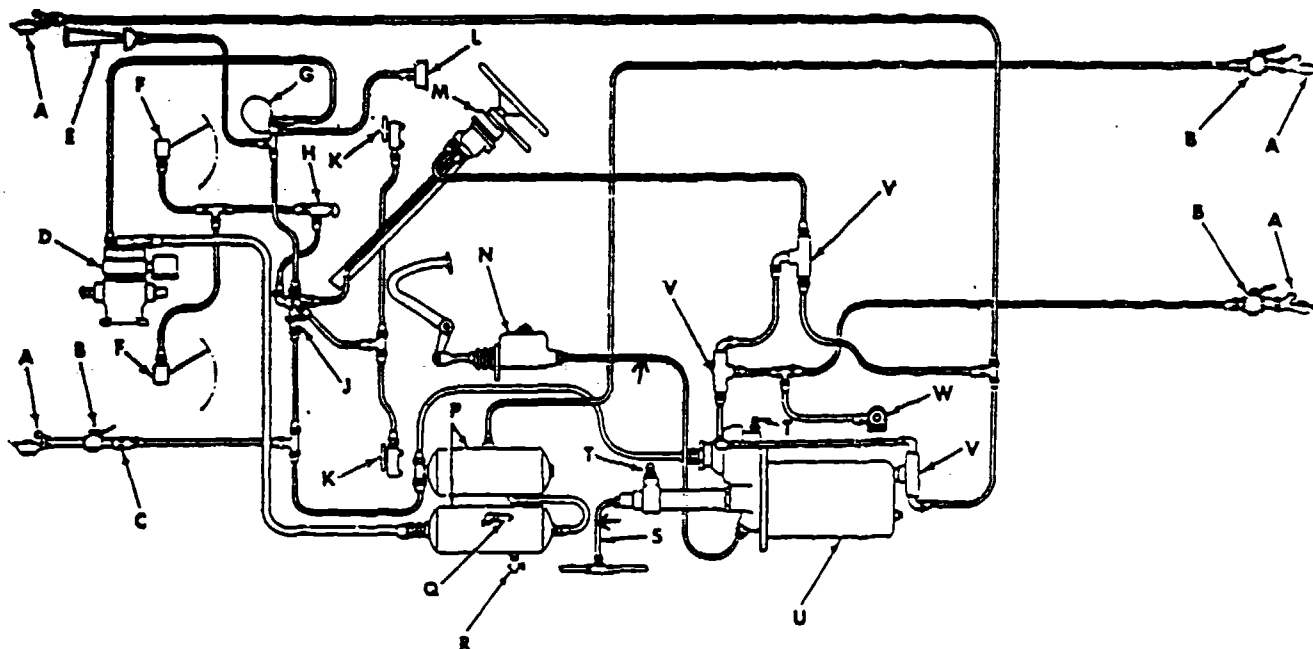


Figure 1: Compressed air system piping diagram

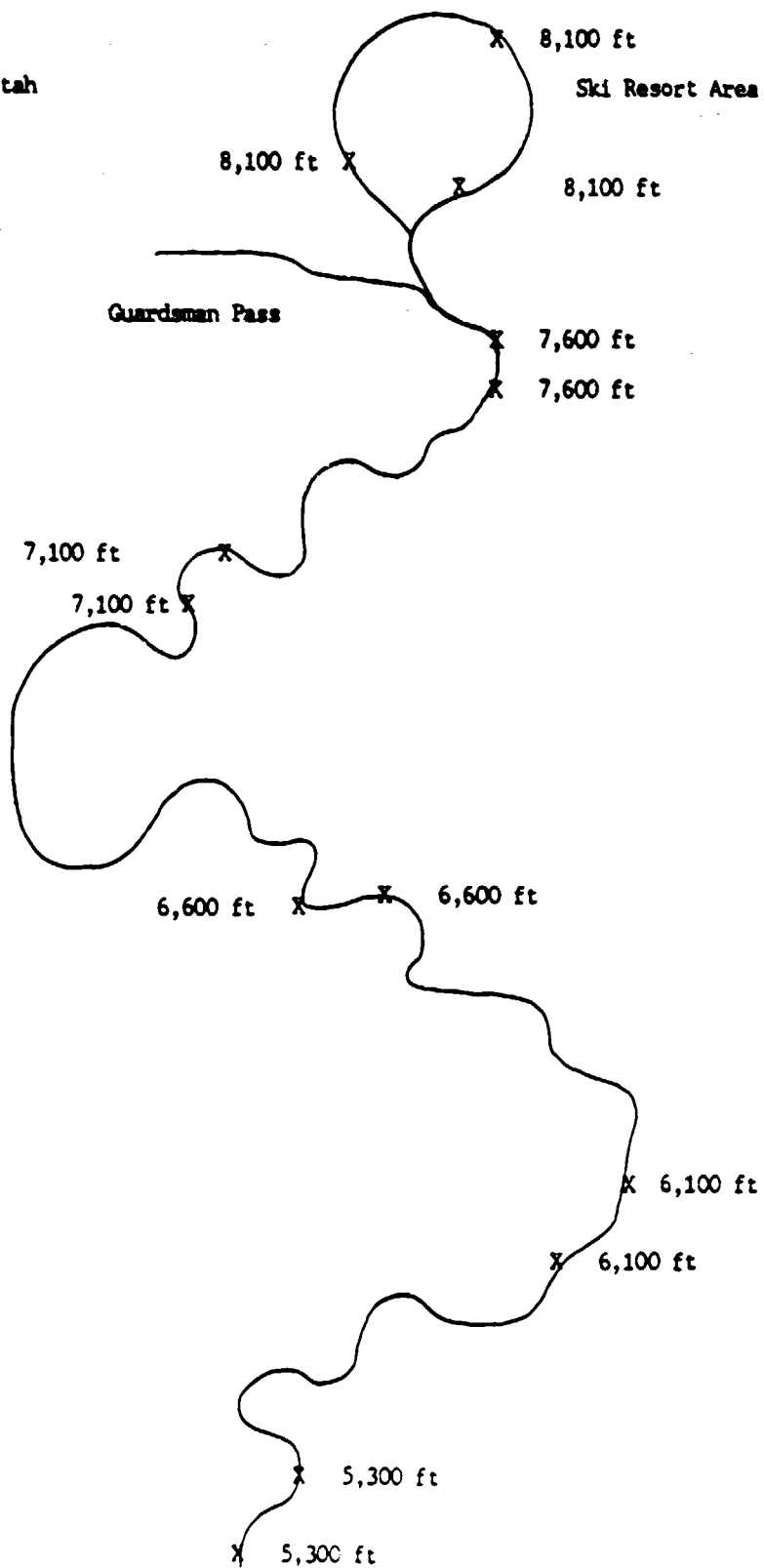
<u>Key</u>	<u>Item</u>	<u>Key</u>	<u>Item</u>
A	Trailer coupling	M	Hand control valve
B	Trailer coupling cutout cock	N	Master cylinder
C	Single check valve	P	Air reservoir
D	Air compressor	Q	Air reservoir safety valve
E	Horn	R	Air reservoir drain cock
F	Windshield wiper	S	Hydraulic line to wheel cylinder
G	Air governor	T	Hydraulic bleeder valve
H	Windshield wiper control valve	U	Air hydraulic brake cylinder
J	Junction block	V	Double check valve
K	Air supply valve	W	Stoplight switch
L	Air pressure gage sending unit		

Figure 1: Compressed air system piping diagram - legend

* Pressure Transducers will be installed in the fluid lines as indicated by the red arrows.

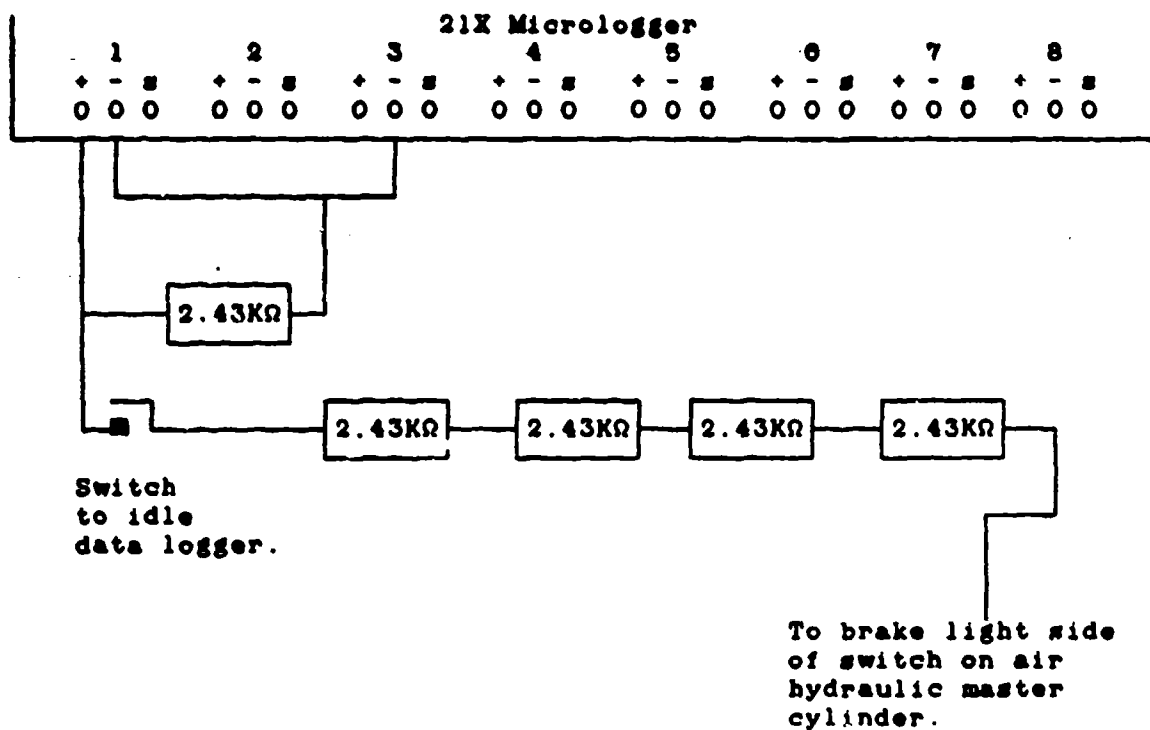
Big Cottonwood Canyon, Utah

X = Prescribed Stop

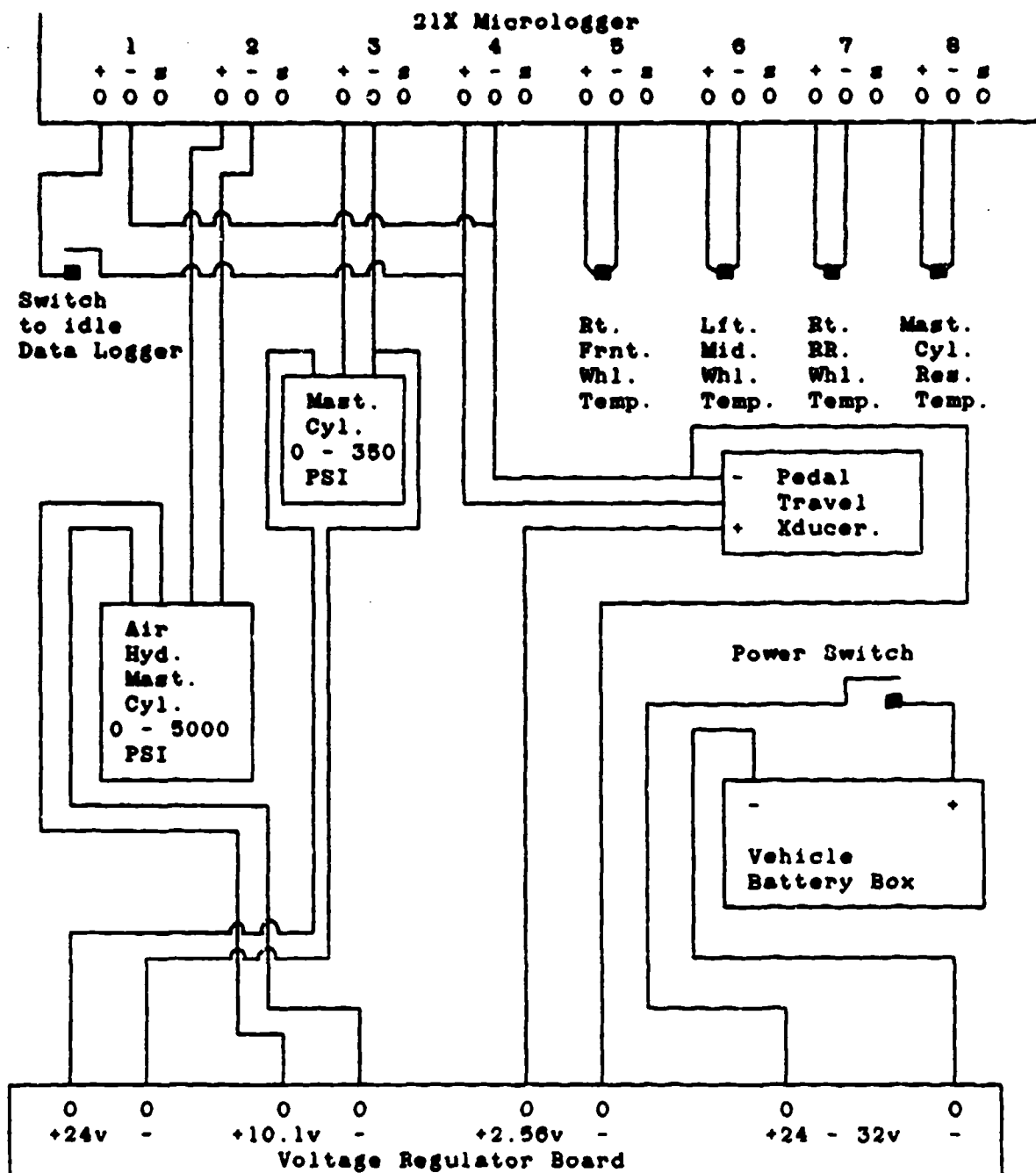


Brake light trigger diagram for data logger.

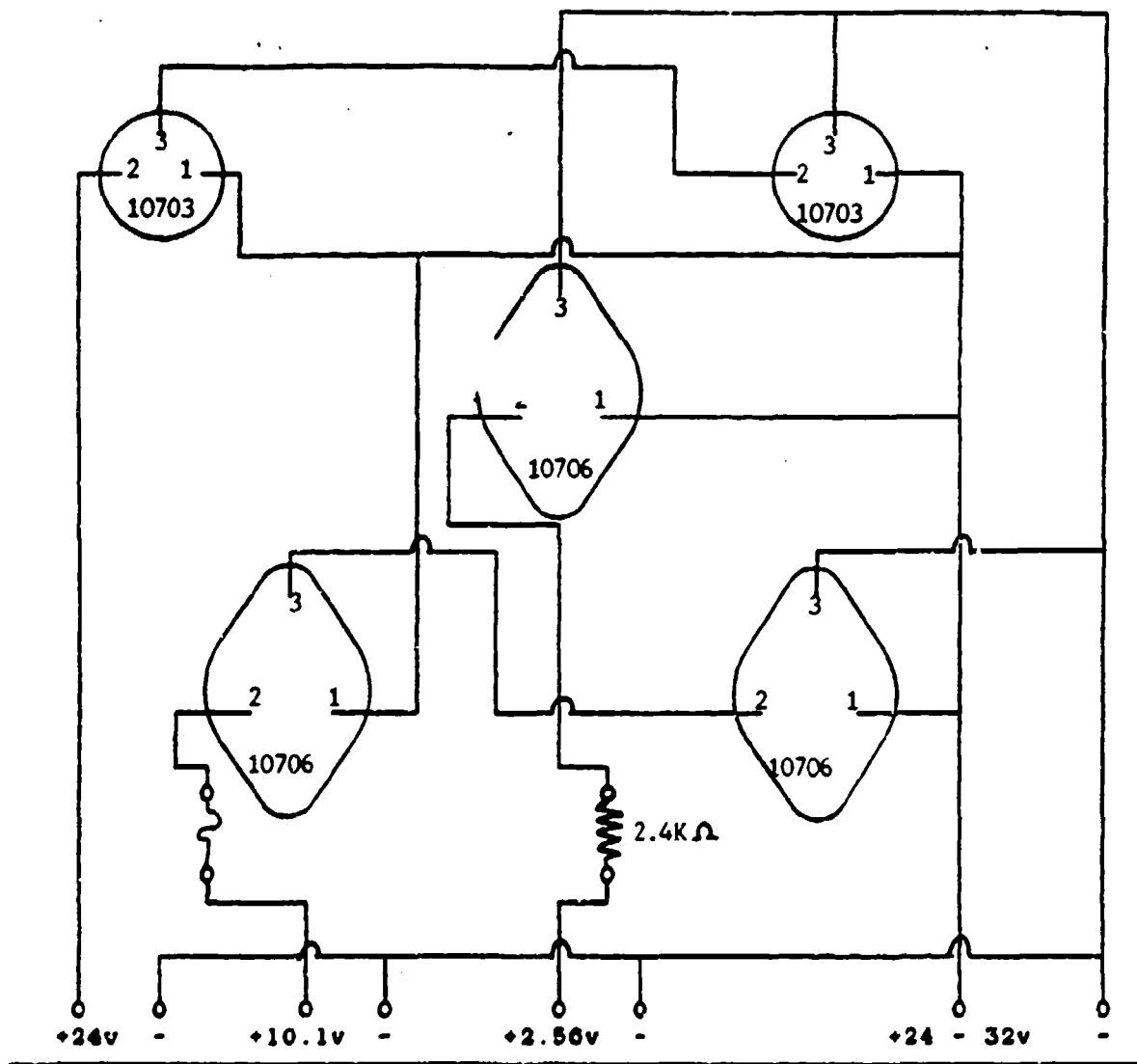
For 2.5 ton trucks.



Voltage Regulator Board, Data Logger, and Instrument Hook up with data logger trigger / idle switch.
For 5 ton trucks.



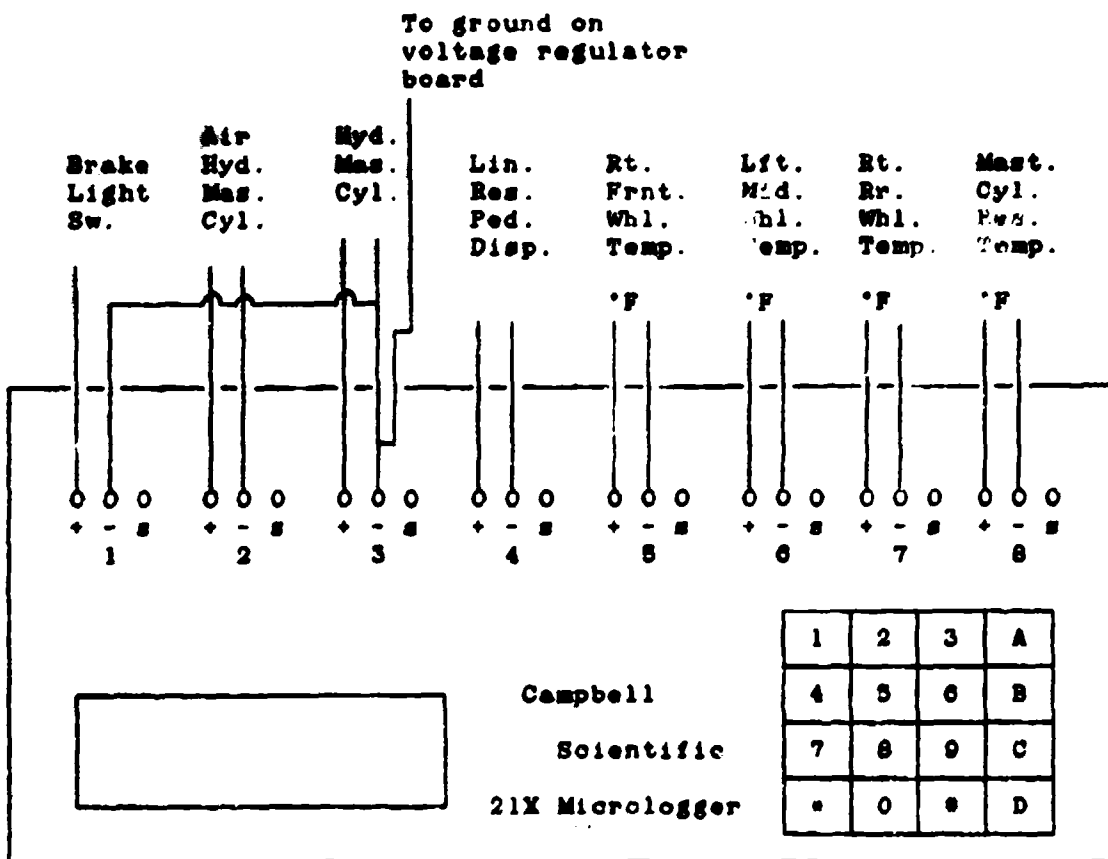
Voltage Regulator Board Schematic



Parts List :

Fiberglass Board 6" x 3 5/8" x 1/16"	(1)	Resistor, 2.4 kΩ ± 1%	(1)
Terminal Strip, 8 connector	(1)	Voltage Regulator, 12 Volt:	
Screws & nuts, 6 - 32 x 1/4"	(6)	JMB38510/10703BXC	(2)
Screws & nuts, 6 - 32 x 1/2"	(2)	or equivalent regulators	
Wire Lugs 22 - 18	(17)	Voltage Regulator, 5 Volt:	
Eyelet Terminal, for 6 - 32 screws	(3)	JMB38510/10706BYC	(3)
Fuse 3/16 amp	(1)	or equivalent regulators	

IX Circuit Hook Up Diagram



linear resistor 10520 (123) 2.63 volt supply 2500 ohms in series
with 2.40k ohms 9.00 in. pedal travel 0% = 0.982 volts 100% =
2.30 volts

position #	displacement inches	output volts
0	0.0000	0.007
1	0.1667	0.092
2	0.3333	0.174
3	0.5000	0.255
4	0.6667	0.339
5	0.8333	0.422
6	1.0000	0.503
7	1.1667	0.588
8	1.3333	0.670
9	1.5000	0.753
10	1.6667	0.836
11	1.8333	0.919
12	2.0000	1.000
13	2.1667	1.083
14	2.3333	1.165
15	2.5000	1.247
16	2.6667	1.328
17	2.8333	1.412
18	3.0000	1.495
19	3.1667	1.574
20	3.3333	1.660
21	3.5000	1.741
22	3.6667	1.824
23	3.8333	1.908
24	4.0000	1.988
25	4.1667	2.072
26	4.3333	2.156
27	4.5000	2.237
28	4.6667	2.320
29	4.8333	2.404
30	5.0000	2.486

inches pedal travel = (6.8283 * volts) - 6.7055

linear resistor 10519 (456) 2.63 volt supply 2500 ohms in series
 with 2.40k ohms 8.75 in. pedal travel 0% = 0.972 volts 100% =
 2.34 volts

position #	displacement inches	output volts
0	0.0000	0.000
1	0.1667	0.075
2	0.3333	0.156
3	0.5000	0.241
4	0.6667	0.322
5	0.8333	0.404
6	1.0000	0.488
7	1.1667	0.572
8	1.3333	0.655
9	1.5000	0.739
10	1.6667	0.823
11	1.8333	0.908
12	2.0000	0.991
13	2.1667	1.073
14	2.3333	1.156
15	2.5000	1.239
16	2.6667	1.322
17	2.8333	1.406
18	3.0000	1.488
19	3.1667	1.573
20	3.3333	1.655
21	3.5000	1.737
22	3.6667	1.820
23	3.8333	1.905
24	4.0000	1.987
25	4.1667	2.069
26	4.3333	2.1
27	4.5000	2.236
28	4.6667	2.317
29	4.8333	2.400
30	5.0000	2.482

inches pedal travel = (6.3963 * volts) - 6.2172

linear resistor 10522 (123) 2.63 volt supply 2500 ohms in series
with 2.40k ohms 7.50 in. pedal travel 0% = 2.27 volts 100% = 0.19
volts

position #	displacement inches	output volts
0	5.0000	0.005
1	4.8333	0.088
2	4.6667	0.172
3	4.5000	0.254
4	4.3333	0.336
5	4.1667	0.419
6	4.0000	0.500
7	3.8333	0.582
8	3.6667	0.667
9	3.5000	0.749
10	3.3333	0.833
11	3.1667	0.917
12	3.0000	1.000
13	2.8333	1.083
14	2.6667	1.166
15	2.5000	1.250
16	2.3333	1.332
17	2.1667	1.415
18	2.0000	1.496
19	1.8333	1.578
20	1.6667	1.662
21	1.5000	1.744
22	1.3333	1.826
23	1.1667	1.907
24	1.0000	1.990
25	0.8333	2.071
26	0.6667	2.152
27	0.5000	2.233
28	0.3333	2.317
29	0.1667	2.397
30	0.0000	2.481

inches pedal travel = $8.1852 + (-3.6057 * \text{volts})$

linear resistor 10521 (123) 2.63 volt supply 2500 ohms in series
with 2.40k ohms 7.25 in. pedal travel 0% = 2.46 volts 100% = 0.22
volts

position #	displacement inches	output volts
0	5.0000	0.100
1	4.8333	0.184
2	4.6667	0.263
3	4.5000	0.345
4	4.3333	0.427
5	4.1667	0.512
6	4.0000	0.591
7	3.8333	0.676
8	3.6667	0.756
9	3.5000	0.839
10	3.3333	0.920
11	3.1667	1.001
12	3.0000	1.086
13	2.8333	1.166
14	2.6667	1.248
15	2.5000	1.329
16	2.3333	1.412
17	2.1667	1.495
18	2.0000	1.577
19	1.8333	1.660
20	1.6667	1.741
21	1.5000	1.825
22	1.3333	1.905
23	1.1667	1.986
24	1.0000	2.069
25	0.8333	2.150
26	0.6667	2.234
27	0.5000	2.315
28	0.3333	2.396
29	0.1667	2.477
30	0.0000	2.559

inches pedal travel = $7.9639 + (-3.2380 * \text{volts})$

GENISCO Model SP 500 SN: 85 - 806, 24 volt supply

position #	applied psig	output volts
0	0.0	0.010
1	30.0	0.525
2	60.0	1.019
3	90.0	1.515
4	120.0	2.023
5	150.0	2.521
6	180.0	3.031
7	210.0	3.515
8	240.0	4.014
9	270.0	4.515
10	300.0	5.025
11	330.0	5.503
12	350.0	5.825
13	0.0	0.012

PSI = -1.3841 + (output) * 0.06014

Calibration Data Pressure Transducers 0 - 350 PSI

GENISCO Model SP 500 SN: 85 - 803, 24 volt supply

position #	applied psig	output volts
0	0.0	0.033
1	30.0	0.544
2	60.0	1.052
3	90.0	1.559
4	120.0	2.066
5	150.0	2.572
6	180.0	3.079
7	200.0	3.414
8	210.0	3.530
9	240.0	4.035
10	260.0	4.370
11	290.0	4.870
12	300.0	5.025
13	320.0	5.350
14	350.0	5.835
15	0.0	0.028

$$PSI = -3.8372 + (\text{output}) * 0.06037$$

GENISCO Model SP 500 SN: 85 - 805, 24 volt supply

position #	applied psig	output volts
0	0.0	0.114
1	30.0	0.611
2	60.0	1.120
3	90.0	1.640
4	120.0	2.128
5	150.0	2.616
6	180.0	3.121
7	210.0	3.602
8	240.0	4.112
9	270.0	4.606
10	300.0	5.082
11	330.0	5.592
12	350.0	5.906
13	0.0	0.110

$$PSI = -7.8561 + (\text{output}) * 0.06043$$

Calibration Data Pressure Transducers 0 - 5000 PSI

BLH Model SR-4 GP 5000 SN: 19383, 10.1 volt supply

position #	applied psig	output millivolts
0	0.0	0.05
1	100.0	0.70
2	200.0	1.32
3	300.0	1.93
4	500.0	3.13
5	700.0	4.32
6	800.0	4.95
7	1000.0	6.15
8	1200.0	7.40
9	1400.0	8.62
10	1500.0	9.21
11	1700.0	10.44
12	2000.0	12.30
13	2200.0	13.43
14	2500.0	15.30
15	2700.0	16.43
16	3000.0	18.24

$$\text{PSI} = -16.215 + (\text{output}) * 164.842$$

Calibration Data Pressure Transducers 0 - 5000 PSI

BLH Model SR-4 GP 5000 SN: 19442, 10.1 volt supply

position #	applied psig	output millivolts
0	0.0	-0.38
1	100.0	0.27
2	200.0	0.91
3	300.0	1.52
4	500.0	2.70
5	700.0	3.94
6	800.0	4.55
7	1000.0	5.70
8	1200.0	6.98
9	1400.0	8.22
10	1500.0	8.81
11	1700.0	10.00
12	2000.0	11.84
13	2200.0	12.98
14	2500.0	14.86
15	2700.0	16.02
16	3000.0	17.82

$$\text{PSI} = 52.279 + (\text{output}) * 164.993$$

Calibration Data Pressure Transducers 0 - 5000 PSI

BLH Model SR-4 GP 5000 SN: 19393, 10.1 volt supply

position #	applied psig	output millivolts
0	0.0	-0.25
1	100.0	0.45
2	200.0	1.02
3	300.0	1.63
4	500.0	2.80
5	700.0	4.04
6	800.0	4.70
7	1000.0	5.88
8	1200.0	7.13
9	1400.0	8.31
10	1500.0	8.92
11	1700.0	10.13
12	2000.0	11.96
13	2200.0	13.18
14	2500.0	14.99
15	2700.0	16.17
16	3000.0	17.93

$$\text{PSI} = 31.005 + (\text{output}) * 164.919$$

Calibration Data Pressure Transducers 0 - 5000 PSI

BLH Model SR-4 GP 5000 SN: 51823, 10.1 volt supply

position #	applied psig	output millivolts
0	0.0	-0.25
1	100.0	0.49
2	200.0	1.05
3	300.0	1.63
4	500.0	2.84
5	700.0	4.05
6	800.0	4.67
7	1000.0	5.86
8	1200.0	7.11
9	1400.0	8.34
10	1500.0	8.90
11	1700.0	10.15
12	2000.0	11.93
13	2200.0	13.14
14	2500.0	14.99
15	2700.0	16.11
16	3000.0	18.00

$$\text{PSI} = 29.234 + (\text{output}) * 165.127$$

Pressure Transducers, 0 - 350 PSI 0.5%

2.5 ton truck poly glycol transducer SN: 85-805
12 volt supply PSI = $-7.8561 + (\text{output}) \times 0.06043$

2.5 ton truck silicon transducer SN: 85-803
12 volt supply PSI = $-3.8372 + (\text{output}) \times 0.06037$

5 ton truck poly glycol transducer SN: 85-806
12 volt supply PSI = $-1.3841 + (\text{output}) \times 0.06014$

5 ton truck silicon transducer SN: 85-803
12 volt supply PSI = $-3.8372 + (\text{output}) \times 0.06037$

Pressure Transducers, 0 - 5000 PSI 2 %

2.5 ton truck poly glycol transducer SN: 19442
10.1 volt supply PSI = $52.279 + (\text{output}) \times 164.993$

2.5 ton truck silicon transducer SN: 51823
10.1 volt supply PSI = $29.234 + (\text{output}) \times 165.127$

5 ton truck poly glycol transducer SN: 19393
10.1 volt supply PSI = $31.005 + (\text{output}) \times 164.919$

5 ton truck silicon transducer SN: 19383
10.1 volt supply PSI = $-16.215 + (\text{output}) \times 164.842$

Displacement Transducers, Linear Resistor

2.5 ton truck poly glycol transducer SN: 10521 leads: (123)
2.63 volt supply, 7.25 in. pedal travel 0% = 2.46volts 100% = 0.22volts
inches pedal travel = $7.9639 + (-3.2380 \times \text{volts})$

2.5 ton truck silicon transducer SN: 10522 leads: (123)
2.63 volt supply 7.50 in. pedal travel 0% = 2.27volts 100% = 0.19volts
inches pedal travel = $8.1852 + (-3.6057 \times \text{volts})$

5 ton truck poly glycol transducer SN: 10519 leads: (456)
2.63 volt supply 8.50 in piston travel 0% = 0.972volts 100% = 2.34volts
inches pedal travel = $(6.3963 \times \text{volts}) - 6.2172$

5 ton truck silicon transducer SN: 10520 leads: (123)
2.63 volt supply 8.75 in piston travel 0% = 0.982volts 100% = 2.30volts
inches pedal travel = $(6.8285 \times \text{volts}) - 6.7055$

6 JUL 89
TOD (3)

OBJECTIVE:

```
*1A                                ! Begin Program Table 1

01:D2A                            ! Execution time (in seconds. .2 sec is
                                ! specified, can be changed)
```

```

2A                                     Differential Voltage
01:1A                                1 repetition
02:15A                               Range (5 V, fast)
03:1A                                In channel
04:1A                                Store to location *
05:1A                                Multiplier
06:0A                                Offset

```

```

89A                                     ! If X >= F
                                         ! Input location
01:1A                                  ! Comparison code
02:3A                                  ! 2000 mvols, can be changed
03:2000A                              ! THEN DO
04:30A

```

```

80A                                | DO
                                | Set output flag
01:10A

```

```

77A                                     | Real time option
                                         |
01:111A                               | Day,Hour,Min,Sec

```

87A 1 LOOP

01:1A | Delay
02:60A | Number of iterations

Instruction * 6: (Take reading, channel 1: brake light)

2A | Differential Voltage

01:1A | 1 repetition
02:15A | Range (5 V, fast)
03:1A | Channel
04:1A | Location *
05:1A | Multiplier
06:0A | Offset

Instruction * 7: (Take reading, channel 2: air hydraulic pressure)

2A | Differential Voltage

01:1A | 1 repetition
02:12A | Range (15 mV, fast)
03:2A | Channel
04:2A | Location *
05:163D9A | Multiplier
06:28D98A | Offset

Instruction * 8: (Take reading, channel 3: master cylinder pressure)

2A | Differential Voltage

01:1A | 1 repetition
02:15A | Range (5 V, fast)
03:3A | Channel
04:3A | Location *
05:D0604A | Multiplier
06:3D837CA | Offset

Instruction * 9: (Take reading, channel 4: linear resistor)

2A | Differential Voltage

01:1A | 1 repetition
02:15A | Range (5 V, fast)
03:4A | Channel
04:4A | Location *
05:1A | Multiplier
06:0A | Offset

Instruction * 10:

17A | Reference temperature

01:15A

| Location *

Instruction * 11: (Take readings, channels 5-8: temperatures)

14A

| Temperature measurements

01:4A

| Repetition

02:13A

| Range (50 mV, fast)

03:5A

| In channel

04:1A

| Thermo couple type

05:15A

| Reference temperature

06:5A

| Location *

07:1D8A

| Multiplier

08:32A

| Offset

Instruction * 12:

86A

| DO

01:10A

| Set output flag

Instruction * 13:

70A

| SAMPLE

01:8A

| Location *

02:1A

Instruction * 14:

95A

| END

Instruction * 15:

95A

| END

*5A

| Set time

05:XXA

| Enter current year (EX: 89A)

05:XXXA

| Enter current Julian day

05:XXXXA

| Enter current time HHMM

*0

| End of the program

Note: The 21X can store up to 19328 data in its final memory. There are 544 data per brake application. Therefore, THE MAXIMUM NUMBER OF BRAKE APPLICATION ALLOWED IS 35.

```

1 REM BRAKE FLUID PROGRAM, written by Tien Duong, 9 Jun 89
2 OPTION LIST SUB : OPTION LIST FOR 5 SET CASE OFF
3 Ff$ = CHR$(12) : DIM Df70 : GOTO Menu
4 IF Flag=1 THEN RETURN
5 GOTO 160 : F1 - Load a data file
8 IF Flag=1 THEN RETURN
9 GOTO 1040 : F2 - Display data
12 IF Flag=1 THEN RETURN
13 GOTO 1310 : F3 - Get a copy of a data file
16 IF Flag=1 THEN RETURN : F4 - Plot a customized file
17 Flag = 4
18 GOTO 1540
24 IF Flag=1 THEN RETURN
25 GOTO 340 : F6 - Retrieve data from the Micrologger
28 IF Flag=1 THEN RETURN
29 GOTO 1750 : F7 - Generate graphs
76 GOTO 4140 : Shift F9 - Quit the program
80 GOTO Menu : Shift F10 - Return to main menu
100 Start:
110 SET KEY ON
120 FOR I = 1 TO 500 : NEXT I
130 Screensaver = Screensaver+1
140 IF Screensaver>1500 THEN CLEAR
150 GOTO 120

160 REM LOAD A DATA FILE
170 CLEAR : PRINT "LOAD A DATA FILE"
180 PRINT "=====" : PRINT
190 PRINT "This will erase the current file in use!"
200 INPUT PROMPT "Are you sure you want to do this (Y/N)? ":Choice$
210 IF Choice$="Y" OR Choice$="N" THEN 230
220 GOTO 200
230 IF Choice$="N" THEN GOTO Menu
240 PRINT : INPUT PROMPT "Enter name of the data file? ":Nf$
250 ON ERROR 102 GOTO 1520
260 OPEN #1:Nf$,"R"
270 ON EOF(1) GOTO 330
280 READ #1:Tdate$,Tt$,Sec$
290 FOR I = 1 TO 60
300 READ #1:Bon,X1,X2,X3,X4,X5,X6,X7
310 NEXT I
320 GOTO 250
330 CLOSE #1 : GOTO Menu

340 REM RETRIEVE DATA FROM MICROLOGGER
350 CLEAR : PRINT "RETRIEVE DATA FROM MICROLOGGER"
360 PRINT "=====" : PRINT
370 INPUT PROMPT "Are you sure you want to do this (Y/N)? ":Choice$ : PRINT
380 IF Choice$="Y" OR Choice$="N" THEN 400
390 GOTO 370
400 IF Choice$="N" THEN GOTO Menu
410 PRINT "??? Connect the Micrologger through the RS-232 interface to"
420 PRINT " the computer via COM1 (Communication Port # 1)!" : PRINT
430 PRINT "--> Set the baud rate of 1200 bits/sec by entering"
440 PRINT " "" *4A1A1A "" on the MICROLOGGER." : PRINT
450 INPUT PROMPT "--> Name a file for your data? ":Nf$ : PRINT
460 PRINT "??? The total number of data points is always a multiple"
470 PRINT " of 544 for this application!" : PRINT
480 INPUT PROMPT "--> Enter total number of data points? ":Ndp : PRINT

```

```

490 PRINT "???" The n-th data point is not necessarily"
500 PRINT "    the FIRST data point (dpt)!" : PRINT
510 PRINT "--> Initiate the DUMP command on the MICROLOGGER by entering"
520 PRINT "    " " *9A (from the n-th dpt) A (to the m-th dpt) A1A: ""
530 OPEN #1:"COM1","R"
540 Tnf$ = Nf$ & ".ASC" : OPEN #2:Tnf$,"W"
550 Nbs = Ndp/544 : # of brake applications
560 FOR K = 1 TO Nbs
570     INPUT #1:C$
580     PRINT #2:C$
590     FOR I = 1 TO 60
600         INPUT #1:A$,B$
610         PRINT #2:A$," ",B$
620     NEXT I
630 NEXT K
640 CLOSE #1 : CLOSE #2

650 REM SEPARATION OF DATA
660 Bn = 1 : OPEN #1:Tnf$,"R"
670 ON EOF(1) GOTO 1020
680 OPEN #2:Nf$,"W"
690 INPUT #1:C$
700 Julian$ = SEG$(C$,11,10) : Julian$ = SEG$(Julian$,4,6)
710 Julian = VAL(Julian$)
720 GOSUB Julianday
730 Tt$ = SEG$(C$,21,10) : Tt$ = SEG$(Tt$,4,4)
740 Sec$ = SEG$(C$,31,10) : Sec$ = SEG$(Sec$,4,4)
750 IF Bn>10 THEN 780
760 Bn$ = STR$(Bn) : Bn$ = REP$("",1,1) : Bn$ = "0" & Bn$
770 GOTO 790
780 Bn$ = STR$(Bn) : Bn$ = REP$("",1,1)
790 Bnf$ = Nf$ & ".B" & Bn$
800 OPEN #3:Bnf$,"W"
810 WRITE #3:Tdate$,Tt$,Sec$
820 WRITE #2:Tdate$,Tt$,Sec$
830 FOR I = 1 TO 60
840     INPUT #1:A$
850     Bon$ = SEG$(A$,11,10) : Bon$ = SEG$(Bon$,3,7) : Bon = VAL(Bon$)
860     IF Bon<1000 THEN 890
870     Bon = :
880     GOTO 900
890     Bon = 0
900     Place = 20
910     FOR J = 1 TO 7
920         B$ = SEG$(A$,Place-1,10) : B$ = SEG$(B$,3,7) : B = VAL(B$)
930         IF B<=0 THEN B = 0
940         D(J) = B
950         Place = Place+10
960     NEXT J
970     WRITE #3:Bon,D(1),D(2),D(3),D(4),D(5),D(6),D(7)
980     WRITE #2:Bon,D(1),D(2),D(3),D(4),D(5),D(6),D(7)
990 NEXT I
1000 Bn = Bn+1 : CLOSE #3
1010 GOTO 690
1020 CLOSE #1 : CLOSE #2
1030 GOTO Menu

1040 REM DISPLAY DATA
1050 IF Nf$="" THEN 1070
1060 GOTO 1110

```

```

1070 CLEAR : PRINT "DISPLAY DATA"
1080 PRINT "*****" : PRINT
1090 INPUT PROMPT "Enter name of the data file? ":Nf$
1100 ON ERROR 102 GOTO 1520
1110 OPEN #1:Nf$,"R"
1120 ON EOF(1) GOTO 1270 : Count = 0 : CLEAR
1130 READ #1:Tdate$,Tt$,Sec$
1140 PRINT USING 1280:Tdate$,Tt$,Sec$
1150 PRINT USING "5XFA":H$
1160 FOR I = 1 TO 60
1170     READ #1:Bon,X1,X2,X3,X4,X5,X6,X7
1180     PRINT USING 1290:Bon,X1,X2,X3,X4,X5,X6,X7
1190     Count = Count+1 : IF Count>20 THEN 1220
1200 NEXT I
1210 GOTO 1130
1220 PRINT : INPUT PROMPT "More data (Y/N)? ":Choices$
1230 IF Choices$="Y" OR Choices$="N" THEN 1250
1240 GOTO 1220
1250 IF Choices$="N" THEN GOTO Menu
1260 Count = 0 : CLEAR : GOTO 1200
1270 CLOSE #1
1280 IMAGE 5X8AX4AX4A
1290 IMAGE 5X1D5X7(4D.2D2X)R
1300 GOTO Menu

1310 REM PRINT OUT OF DATA
1320 IF Nf$="" THEN 1340
1330 GOTO 1380
1340 CLEAR : PRINT "OBTAIN A COPY OF A DATA FILE"
1350 PRINT "*****" : PRINT
1360 INPUT PROMPT "Enter name of the data file? ":Nf$
1370 ON ERROR 102 GOTO 1520
1380 OPEN #1:Nf$,"R"
1390 ON EOF(1) GOTO 1500
1400 OPEN #2:"PRN","W"
1410 READ #1:Tdate$,Tt$,Sec$
1420 PRINT #2 USING 1280:Tdate$,Tt$,Sec$
1430 PRINT #2 USING "5XFA":H$
1440 FOR I = 1 TO 60
1450     READ #1:Bon,X1,X2,X3,X4,X5,X6,X7
1460     PRINT #2 USING 1290:Bon,X1,X2,X3,X4,X5,X6,X7
1470 NEXT I
1480 PRINT #2:Ff$
1490 GOTO 1410
1500 PRINT #2:Ff$ : CLOSE #1 : CLOSE #2
1510 GOTO Menu
1520 OFF ERROR ALL : SOUND "t9003g" : PRINT "File does not exist!" : SLEEP :
1530 GOTO Menu

1540 REM PLOT A DATA FILE
1550 CLEAR : PRINT "PLOT A CUSTOMIZED FILE PREVIOUSLY SAVED"
1560 PRINT "*****" : PRINT
1570 PRINT "File must be previously created, customized, and saved!"
1580 INPUT PROMPT "Are you sure you want to do this (Y/N)? ":Choices$
1590 IF Choices$="Y" OR Choices$="N" THEN 1610
1600 GOTO 1580
1610 IF Choices$="N" THEN Menu
1620 INPUT PROMPT "Enter name of the file: ":Nf$
1630 Nf$ = Nf$ & ".MAN"
1640 ON ERROR 102 GOTO 1520

```

```

1450 OPEN #2:Nf$, "R"
1460 READ #2:Ndp : DIM X(Ndp), Y(Ndp)
1470 READ #2:Gh1$, Gh2$, Gh3$, X1b1$, Y1b1$
1480 READ #2:Lh, Lh, Lv, Lv, X, Y : CLOSE #2
1490 GOSUB Graph1
1700 CLEAR : INPUT PROMPT "Get a copy of the graph (Y/N)? ": Choices$
1710 IF Choices$ = "Y" OR Choices$ = "N" THEN 1730
1720 GOTO 1700
1730 IF Choices$ = "N" THEN Menu
1740 GOTO 3940

1750 REM DATA FOR GRAPHS
1760 Gh1$ = " " : Gh2$ = " " : Gh3$ = " " : X1b1$ = " " : Y1b1$ = " "
1770 Brake = 0 : Goption = 0 : Flag = 1
1780 CLEAR : PRINT "GENERATE GRAPHS"
1790 PRINT "===== " : PRINT
1800 PRINT "Source of data: " : PRINT
1810 PRINT "(1) Will be entered at the key board."
1820 PRINT "(2) From a file previously created and saved in Steps (1 or 3)."
1830 PRINT "(3) From a brake application # n th."
1840 PRINT "(4) Return to main menu." : PRINT
1850 INPUT PROMPT "Your selection: " ALTER "4": Choices$
1860 IF Choices$ = "1" OR Choices$ = "2" OR Choices$ = "3" OR Choices$ = "4" THEN 1890
1870 GOTO 1750
1880 Choice = VAL(Choices$)
1890 ON Choice GOTO 1910, 2080, 2190, 1900
1900 GOTO Menu

1910 REM KEY BOARD
1920 CLEAR : PRINT "ENTER DATA POINTS"
1930 PRINT "===== " : PRINT
1940 INPUT PROMPT "Enter # of data points? ": Ndp : PRINT
1950 IF Ndp <= 1 OR Ndp >= 1001 THEN 1970
1960 GOTO 1990
1970 PRINT "Limit from 2-1000 data points! Retry" : PRINT
1980 GOTO 1940
1990 DIM X(Ndp), Y(Ndp)
2000 FOR I = 1 TO Ndp
2010     PRINT "X("; I; ") , Y("; I; ")"; : INPUT X(I), Y(I)
2020     IF X(I) < 0 OR Y(I) < 0 THEN 2040
2030     GOTO 2060
2040     PRINT "Restriction: X, Y > 0 ! Retry" : PRINT
2050     GOTO 2010
2060 NEXT I
2070 GOTO 2890

2080 REM FROM A DATA FILE
2090 INPUT PROMPT "Enter name of the data file? ": Nf$
2100 Nf$ = Nf$ & ".MAN"
2110 ON ERROR 102 GOTO 2450
2120 OPEN #5:Nf$, "R"
2130 READ #5:Ndp
2140 DIM X(Ndp), Y(Ndp)
2150 READ #5:Gh1$, Gh2$, Gh3$, X1b1$, Y1b1$
2160 READ #5:Lh, Lh, Lv, Lv, X, Y : CLOSE #5
2170 GOSUB Graph1
2180 GOTO 3440

2190 REM BRAKE APPLICATION
2200 Brake = 1 : Ndp = 60

```

```

2210 DIM X1Ndp1,Y1Ndp1,C1Ndp1,C2Ndp1,C3Ndp1,C4Ndp1,C5Ndp1
2220 DIM C6Ndp1,C7Ndp1,C8Ndp1
2230 X1 = 0 : Y1 = 0 : C1 = 0 : C2 = 0 : C3 = 0 : C4 = 0 : C5 = 0 : C6 = 0
2240 C7 = 0 : C8 = 0
2250 INPUT PROMPT "Enter name of the data file? ":Nf$
2260 INPUT PROMPT "Enter the brake application number? ":Bn
2270 IF Bn>=0 OR Bn<=35 THEN 2290
2280 GOTO 2260
2290 INPUT PROMPT "Enter time interval between readings (in second)? ":Rate
2300 FOR I = 1 TO Ndp1 : X1[I] = I*Rate : NEXT I
2310 Bn$ = STR$(Bn) : Bn$ = REP$(" ",1,1)
2320 IF Bn>=10 THEN 2350
2330 Bn$ = "0" & Bn$
2340 GOTO 2350
2350 ON ERROR 102 GOTO 2450
2360 Nf$ = Nf$ & ".B" & Bn$
2370 OPEN #5:Nf$,"R"
2380 READ #5:Tdate$,Tt$,Sec$
2390 FOR I = 1 TO 60
2400     READ #5:Bon,X1,X2,X3,X4,X5,X6,X7
2410     C1[I] = Bon : C2[I] = X1 : C3[I] = X2 : C4[I] = X3 : C5[I] = X4
2420     C6[I] = X5 : C7[I] = X6 : C8[I] = X7
2430 NEXT I : CLOSE #5
2440 GOTO 2470
2450 OFF ERROR ALL : SOUND "t9003g" : PRINT "File does not exist!" : SLEEP 1
2460 GOTO 1750
2470 CLEAR : PRINT "GRAPHS FROM A BRAKE APPLICATION"
2480 PRINT "===== " : PRINT
2490 Decision$ = "123456789"
2500 PRINT "(1) Brake on/off."
2510 PRINT "(2) Air hydraulic pressure."
2520 PRINT "(3) Master cylinder pressure."
2530 PRINT "(4) Linear resistor."
2540 PRINT "(5) Front wheel temperature."
2550 PRINT "(6) Middle wheel temperature."
2560 PRINT "(7) Rear wheel temperature."
2570 PRINT "(8) Fluid temperature."
2580 PRINT "(9) Return to previous menu." : PRINT
2590 INPUT PROMPT "Select the Y() data: " ALTER "9":Choice$
2600 FOR I = 1 TO 9
2610     I$ = SEG$(Decision$,I,1)
2620     IF Choice$<>I$ THEN 2650
2630     Found = 1
2640     EXIT
2650 NEXT I
2660 IF Found=1 THEN 2680
2670 GOTO 2470
2680 Choice = VAL(Choice$)
2690 ON Choice GOTO 2700,2720,2740,2760,2780,2800,2820,2840,2860
2700 Y = C1
2710 GOTO 2850
2720 Y = C2
2730 GOTO 2850
2740 Y = C3
2750 GOTO 2850
2760 Y = C4
2770 GOTO 2850
2780 Y = C5
2790 GOTO 2850
2800 Y = C6

```

```

2810 GOTO 2850
2820 Y = C7
2830 GOTO 2850
2840 Y = C8
2850 GOTO 2860
2860 Brake = 0
2870 GOTO 1750

2880 REM GRAPH SCALES
2890 CLEAR : PRINT "GRAPH SCALES"
2900 PRINT "*****" : PRINT
2910 INPUT PROMPT "Do you prefer an auto scale (Y/N)? ": Choices$
2920 IF Choices$="Y" OR Choices$="N" THEN 2940
2930 GOTO 2910
2940 IF Choices$="Y" THEN 3040
2950 PRINT "X & Y RANGES" : PRINT : PRINT
2960 PRINT "*****"
2970 PRINT "ENTER THE X-RANGE:"
2980 INPUT PROMPT "Lower Limit: ": Lh
2990 INPUT PROMPT "Upper Limit: ": Uh : PRINT
3000 PRINT "ENTER THE Y-RANGE:"
3010 INPUT PROMPT "Lower Limit: ": Lv
3020 INPUT PROMPT "Upper Limit: ": Uv : PRINT : PRINT
3030 GOTO 3260

3040 REM MIN & MAX (AUTO SCALE)
3050 Lh = X[1] : Uh = X[1] : Lv = Y[1] : Uv = Y[1]
3060 FOR I = 1 TO Ndp
3070     IF X[I]>=Lh THEN 3100
3080     Lh = X[I]
3090     GOTO 3110
3100     Lh = Lh
3110     IF X[I]>=Uh THEN 3140
3120     Uh = Uh
3130     GOTO 3150
3140     Uh = X[I]
3150 NEXT I
3160 FOR I = 1 TO Ndp
3170     IF Y[I]>=Lv THEN 3200
3180     Lv = Y[I]
3190     GOTO 3210
3200     Lv = Lv
3210     IF Y[I]>=Uv THEN 3240
3220     Uv = Uv
3230     GOTO 3250
3240     Uv = Y[I]
3250 NEXT I
3260 INP PRG "Do you wish to create/modify headings & labels (Y/N)? ": Choice$
3270 IF Choice$="Y" OR Choice$="N" THEN 3290
3280 GOTO 3260
3290 IF Choice$="N" THEN 3430

3300 REM HEADINGS & LABELS
3310 CLEAR : PRINT "GRAPH TITLE, SUB-TITLES, X & Y LABELS"
3320 PRINT "*****" : PRINT
3330 PRINT "*** You can enter 3 lines of text (60 char/line). "
3340 PRINT "*** Press Return for a blank line." : PRINT
3350 PRINT "Main Title:" : INPUT LINE Gh1$
3360 PRINT "Sub-Title #1:" : INPUT LINE Gh2$
3370 PRINT "Sub-Title #2:" : INPUT LINE Gh3$ : PRINT

```

```

3380 PRINT "X & Y LABELS"
3390 PRINT "*****" : PRINT
3400 PRINT "Enter X-Label (60 char):" : INPUT LINE X1b1$
3410 PRINT "Enter Y-Label (20 char):" : INPUT LINE Y1b1$

3420 REM PLOT GRAPH:
3430 GOSUB Graph1

3440 REM GRAPH OPTIONS
3450 CLEAR : PRINT "GRAPH OPTIONS"
3460 PRINT "*****" : PRINT
3470 PRINT "(1) Replot the previous graph."
3480 PRINT "(2) Reset X,Y ranges, then replot."
3490 PRINT "(3) Modify headings and labels, then replot."
3500 PRINT "(4) Send graph to printer."
3510 PRINT "(5) Send graph to plotter."
3520 PRINT "(6) Save the graph to a file."
3530 PRINT "(7) Return to previous menu." : PRINT
3540 INPUT PROMPT "Your choice: " ALTER "7":Choice$ : PRINT
3550 Decision$ = "1234567"
3560 FOR I = 1 TO 7
3570     I$ = SEG$(Decision$,I,1)
3580     IF Choice$ <> I$ THEN 3610
3590     Found = 1
3600     EXIT
3610 NEXT I
3620 IF Found=1 THEN 3640
3630 GOTO 3450
3640 Choice = VAL(Choice$)
3650 ON Choice GOTO 3660,3680,3870,3950,4050,4060,4120
3660 GOSUB Graph1
3670 GOTO 3450
3680 CLEAR : PRINT "NEW X & Y RANGES"
3690 PRINT "*****" : PRINT
3700 PRINT "(1) X Range only."
3710 PRINT "(2) Y Range only."
3720 PRINT "(3) Both X and Y Ranges." : PRINT
3730 INPUT PROMPT "Your choice: " ALTER "2":Choice$ : PRINT : PRINT
3740 IF Choice$="1" OR Choice$="2" OR Choice$="3" THEN 3760
3750 GOTO 3680
3760 Choice = VAL(Choice$)
3770 ON Choice GOTO 3780,3820,3780
3780 PRINT "ENTER THE X-RANGE:"
3790 INPUT PROMPT "Lower Limit: " :LH
3800 INPUT PROMPT "Upper Limit: " :UH : PRINT
3810 IF Choice=1 THEN 3850
3820 PRINT "ENTER THE Y-RANGE:"
3830 INPUT PROMPT "Lower Limit: " :LV
3840 INPUT PROMPT "Upper Limit: " :UV : PRINT : PRINT
3850 GOSUB Graph1
3860 GOTO 3440
3870 CLEAR : PRINT "MODIFY HEADINGS AND LABELS"
3880 PRINT "*****" : PRINT
3890 INPUT PROMPT "Are you sure you want to do this (Y/N)? " :Choice$
3900 IF Choice$="Y" OR Choice$="N" THEN 3920
3910 GOTO 3890
3920 IF Choice$="N" THEN 3440
3930 GOTO 3300

3940 REM GRAPH TO PRINTER

```

```

3950 Gostick = 2 : SET GRAPH DEVICE "IBMPRN"
3960 SET GRAPH 2,0 : SET GRAPH 0,810 : SET GRAPH 1,720
3970 SET GRAPH DEVICE "IBMPRN"
3980 GOSUB Graph:
3990 COPY
4000 SET GRAPH DEVICE
4010 OPEN #2:"PRN","W" : PRINT #2:Ff$,Ff$ : CLOSE #2
4020 IF Flag=4 THEN Menu : From (F4)
4030 GOTO 4120

4040 REM GRAPH TO PLOTTER
4050 PRINT "Not available!" : SLEEP 1 : GOTO 3450

4060 REM SAVE GRAPH TO A FILE
4070 PRINT : INPUT PROMPT "Enter a file name: " :Nf$
4080 Nf$ = Nf$ & ".MAN" : OPEN #5:Nf$,"W"
4090 WRITE #5:Ndp
4100 WRITE #5:Gh1$,Gh2$,Gh3$,Xlbl$,Ylbl$
4110 WRITE #5:Lh,Uh,Lv,Uv,X,Y : CLOSE #5
4120 IF Brake=1 THEN 2470
4130 GOTO 1750
4140 END ! End of main program

4150 REM JULIAN SUBROUTINE
4160 JulianDay:
4170 DIM Mth[12] : Yy$ = DATE : Yy$ = SEG$(Yy$,8,2)
4180 Yy = VAL(Yy$) : Leap = MOD(Yy,4)
4190 IF Leap=0 THEN RESTORE 4220
4200 IF Leap>=0 THEN RESTORE 4210
4210 DATA 31,28,31,30,31,30,31,31,30,31,30,31
4220 DATA 31,29,31,30,31,30,31,31,30,31,30,31
4230 READ Mth
4240 Days = 0
4250 FOR I = 1 TO 12
4260     IF Julian<=Days+Mth[I] THEN 4290
4270     Days = Days+Mth[I]
4280     GOTO 4370
4290     Tmth = I : Tday = Julian-Days
4300     Tmth$ = STR$(Tmth) : Tmth$ = REP$("",1,1)
4310     Tday$ = STR$(Tday) : Tday$ = REP$("",1,1)
4320     IF Tmth>9 THEN 4340
4330     Tmth$ = "0" & Tmth$
4340     IF Tday>9 THEN 4360
4350     Tday$ = "0" & Tday$
4360     I = 12
4370 NEXT I
4380 Tdate$ = Tmth$ & "/" & Tday$ & "/" & Yy$
4390 RETURN

4400 REM GRAPH1 SUBROUTINE & SELECT VIEWPORT AND WINDOW
4410 Graph1:
4420 CLEAR : Xint = (Uh-Lh)*0.1 : Yint = (Uv-Lv)*0.1
4430 SET VIEWPORT 26,140,15,80
4440 SET WINDOW Lh,Uh,Lv,Uv

4450 REM AXIS & TIC MARKS
4460 SET LINE COLOR 11 : Light cyan
4470 PLOT AXIS Xint,Yint,Lh,Lv,3,3
4480 PLOT AXIS 0,0,Uh,Uv

```

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4490 REM PLOT DATA & RESET VIEWPORT
4500 SET LINE COLOR 12 : Light red
4510 PLOT X,Y
4520 SET VIEWPORT 0,146,0,100
4530 SET WINDOW 0,146,0,100
4540 SET TEXT SIZE 2,1
4550 X0$ = STR$(Lh) : X0$ = REP$("",1,1)
4560 Mx = Xint*5+Lh : X5$ = STR$(Mx) : X5$ = REP$("",1,1)
4570 Ex = Xint*10+Lh : X10$ = STR$(Ex) : X10$ = REP$("",1,1)
4580 Y0$ = STR$(Lv) : Y0$ = REP$("",1,1)
4590 My = Yint*5+Lv : Y5$ = STR$(My) : Y5$ = REP$("",1,1)
4600 Ey = Yint*10+Lv : Y10$ = STR$(Ey) : Y10$ = REP$("",1,1)
4610 SET TEXT COLOR 11 : Light cyan
4620 MOVE 25,11 : PLOT TEXT USING "5A":X0$
4630 MOVE 81,11 : PLOT TEXT USING "5A":X5$
4640 MOVE 137,11 : PLOT TEXT USING "5A":X10$
4650 MOVE 16,15 : PLOT TEXT USING "5A":Y0$
4660 MOVE 16,47 : PLOT TEXT USING "5A":Y5$
4670 MOVE 16,78 : PLOT TEXT USING "5A":Y10$

4680 REM DRAW LABELS
4690 SET TEXT COLOR 14 : SET TEXT ALIGN 3,3 : MOVE 94,6.5
4700 PLOT TEXT X1b1$
4710 SET TEXT ALIGN 0,0
4720 SET TEXT PATH 3
4730 MOVE 10,78 : PLOT TEXT Y1b1$ : SET TEXT PATH 0

4740 REM DRAW HEADINGS
4750 SET TEXT ALIGN 3,3 : SET TEXT COLOR 13 : Light magenta
4760 MOVE 74,92 : PLOT TEXT Gh1$
4770 MOVE 74,88 : PLOT TEXT Gh2$
4780 MOVE 74,84 : PLOT TEXT Gh3$
4790 SET TEXT ALIGN 0,0 : SET LINE COLOR 9 : Light blue
4800 MOVE 5,5 : RDRAW 143,0 : RDRAW 0,90 : RDRAW -143,0 : RDRAW 0,-90
4810 IF Goption=2 THEN 4830
4820 INPUT PROMPT "Press Return key to continue..." ALTER " ":Choice$
4830 Goption = 0
4840 SET TEXT COLOR 15 : SET LINE COLOR 15
4850 RETURN

4860 REM MENU
4870 Menu:
4880 CLEAR : PRINT USING "10XFA":"*****"
4890 PRINT USING "10XFA": "* BRAKE FLUID TESTING PROGRAM *"
4900 PRINT USING "10XFA":"*****" : PRINT : PRINT
4910 PRINT " SELECT A FUNCTION KEY:" : PRINT
4920 PRINT " (F1) LOAD A DATA FILE."
4930 PRINT " (F2) DISPLAY DATA ON SCREEN."
4940 PRINT " (F3) GET A COPY OF A DATA FILE."
4950 PRINT " (F4) PLOT A CUSTOMIZED FILE PREVIOUSLY SAVED IN (F7)."
4960 PRINT " (F6) RETRIEVE DATA FROM THE MICROLOGGER 21X."
4970 PRINT " (F7) GENERATE GRAPHS."
4980 PRINT " SHIFT (F9) QUIT THE PROGRAM."
4990 PRINT " SHIFT (F10) RETURN TO MAIN MENU."
5000 H$ = "BRAKE P AHYD P MOYL L RES F WHL F WHL R WHL"
5010 H$ = H$ & " FLUID"
5020 Nf$ = "" : Screensaver = 0 : Flag = 0
5030 GOTO Start

```

Appendix F

Dissolved Air Bench Test Procedure

SILICONE BRAKE FLUID: BENCH TEST FOR DISSOLVED AIR

BACKGROUND AND INTRODUCTION:

This test plan will investigate the possibility, on a qualitative level, that silicone brake fluid releases air upon subjection to the lower atmospheric pressures encountered at higher altitudes. The test will involve three phases. The first phase will consist of exposing a sample of silicone brake fluid to continuously decreasing pressures; the second phase will involve subjecting the sample to continuously increasing pressures starting from the lowest pressure achieved in phase one; and the final phase will consist of exposing the fluid to a series of decreased pressures for a specified period of time. Each phase will be repeated for a sample of polyglycol brake fluid to allow comparisons of behavior between the two fluids.

PROCEDURE:

PHASE ONE... Place 15 ml of silicone brake fluid into the 25 ml flask. Set vacuum oven temperature to 25°C. Weigh the flask with the fluid and record the weight. Transfer flask to vacuum oven and position so that the flask and its entire contents can be seen clearly through the window. Seal the oven and begin drawing a vacuum on the chamber. Following the values listed in the chart below, drop the pressure to each given value and allow the flask to stay at each pressure for 5 minutes. Observe any appearance of bubbles issuing from the fluid. As this test is qualitative in nature, use best judgement as to how to describe the volume of bubbles, if any, appearing in the fluid.

PHASE TWO... Allow the flask to stay at the final pressure for 10 minutes, then bring the oven back to atmospheric pressure as soon as possible and quickly weigh the sample. Note weight change, if any. Place sample in oven and drop the pressure once again to the lowest pressure value. Let the flask sit at this pressure for 5 minutes, then increase the pressure to the next value. Let the flask sit for 5 minutes and increase the pressure. Repeat this procedure until atmospheric pressure is once again achieved. Weigh the flask again and note weight difference, if any.

PHASE THREE... Place the flask in the oven and drop the pressure to the lowest value and allow the flask to sit at this pressure for 1.5 hours. Bring the oven back to atmospheric pressure as soon as possible and quickly weigh flask as before, noting any weight change. Place the flask in the oven once again, and drop the pressure only half way

to the lowest value. Let the flask sit for 1.5 hours and weigh as before.

Repeat the entire procedure with a 15 ml sample of the polyglycol brake fluid, noting any changes in appearance or weight. In an attempt to test the one-way valves normally found on 5-ton trucks, repeat the entire procedure for both fluids using the 25 ml flask equipped with the one-way valve and rubber stopper. Carefully note all changes in appearance and weight. It is desirous to compare both fluid when open to the atmosphere and when subjected to the valve action.

Appendix G

Air Entrainment Report

SILICONE BRAKE FLUID AIR ENTRAINMENT ANALYSIS

by

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31 March 1989

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SILICONE BRAKE FLUID AIR ENTRAINMENT ANALYSIS

INTRODUCTION

- PURPOSE:** The purpose of this experiment is to determine the air entrainment propensities of various silicone brake fluids to determine if these properties cause a problem in braking systems of military vehicles.
- BACKGROUND:** From what is contained in the Utah National Guard Memo of 9 January 1989, it is inferred that silicone brake fluid (SBF) entrains air. Limited testing was conducted in 1981 at Belvoir RD&E Center and results indicated that SBF is less prone to entrain air than the previously used conventional polyglycol fluids. According to the memo, however, the present silicone brake fluids used in 2 1/2 and 5 ton trucks are causing failures in the brake systems. As per the memo,
- "... the main disadvantage of silicone is its affinity for air... With air in the system and when the fluid is under pressure when braking, it absorbs the air which causes an air/hydraulic problem"
- "... silicone boils off, more severe at higher temperatures... when the fluid boils off, a void is created and replaced with air or water"
- SCOPE:** To more fully quantify the February 1982 information reported on in report #2348, "Evaluation of the Flush/Fill and High Pressure Air Purge Procedures for Converting Army Vehicles to Silicone Brake Fluid", by Messrs. Chapin, Conley, and Jamison, entrainment testing via ASTM D 3427 (Gas Bubble Separation Time of Petroleum Oils) will be performed to measure the ability of fluids to separate entrained air. Testing will be conducted at atmospheric pressure at specified temperatures. It is important to note that this experiment will only determine entrained air, not dissolved air. Mixtures of the SBF contaminated by the polyglycol will be tested in the same manner as the pure samples. In addition, a quick qualitative test will be conducted on each fluid sample to determine if any air has been dissolved in the fluid. No effort will be made at this time to determine the volume of air, if any, that has been dissolved.

OBJECTIVES:

The primary objective of this experiment is to determine with acceptable repeatability, the gas bubble separation time for the following samples via the ASTM D 3427 procedure:

Silicone Brake fluids (new)...

- * SBF Mil-B-46176
Qual. # SBF-1001
Manf. # 475-195 GE
- * SBF Mil-B-46176
Qual. # SBF-1000
Manf. # X2-1143 Dow Corning
- * SBF Mil-B-46176
Qual. # SBF-1003
Manf. # P1615-129 Delco Moraine

Conventional Polyglycol Brake Fluids...

- * HDCP VV-B-680
Qual. # M-9316
Manf. # HDCP-420 Olin Corp.
- * HDCP VV-B-680
Qual. # M-9317
Manf. # HDCP-470 Olin Corp.

In addition to the single component samples listed above, gas bubble separation times will be recorded for mixtures of the SBF and polyglycol samples in a specified concentration:

SBF:Polyglycol - 90:10

PROJECT CONCEPT AND PROCEDURES**CONCEPT:**

This test will determine whether or not silicone brake fluids entrain air to an appreciable extent such that the braking system in military vehicles is jeopardized. The time required for the fluids to release air that has been introduced into the fluid will be recorded for each of the above samples and indicated mixtures. From this data it can be determined if air entrainment by silicone brake fluids presents a problem for operation of military vehicles. In addition, each sample

will be placed under vacuum in order to determine if there is any dissolved air in the fluid. This experiment will simply indicate whether further testing is required to study the effects of dissolved air in the fluid when it is in use in the brake systems.

PROCEDURE:

AIR ENTRAINMENT... The procedure followed in order to determine the air entrainment propensities of silicone brake fluids is the ASTM Standard Test for Gas Bubble Separation Time of Petroleum Oils (D 3427-75).

SUMMARY OF METHOD: Compressed air is blown through the test fluid which has been heated to a given temperature of 25 °C, 50 °C, or 75 °C. After the gas flow is stopped, the time required for the gas entrained in the fluid to reduce volume to 0.2% is recorded as the gas bubble separation time.

DEFINITION: Gas Bubble Separation Time... the number of minutes needed for gas entrained in the fluid to reduce in volume to 0.2% under the conditions of this test and at the specified temperature.

PREPARATION OF APPARATUS:

1. Clean the interior of the test vessel, including the gas inlet and sinker, and all other glassware coming in contact with the sample, before each determination in the following manner;
2. Rinse away the fluid residue with ethanol and dry by air blowing.
3. Clean the apparatus by immersing in chromic acid solution for a minimum period of 12 hours in order to remove completely any traces of silicone.
4. Rinse with distilled water.
5. Rinse with acetone and dry with clean compressed air.

TEST METHOD:

1. Assemble the test apparatus as shown in Fig. 1. Set the circulating bath to test temperature. Turn air on but do not fit inlet tube into the test vessel. While air is flowing at proper pressure, adjust temperature controller such that the air stream reaches the test temperature.
2. Warm 200 mL of the fluid in an oven set at a temperature of 10 °C higher than the test temperature.
3. Pour 180 mL of the warmed sample into the test vessel.

4. Allow the sample to reach the test temperature. This usually takes about twenty minutes.
5. Warm the sinker of the density balance to the test temperature in an air bath. When the sinker has reached the test temperature, immerse it in the sample taking care that no air bubbles cling to it. Attach the sinker to the beam of the density balance such that the bottom of the sinker is 10 ± 2 mm from the bottom of the test vessel.
6. Read the density from the balance to the nearest 0.001 g/mL and record it as the initial density, d_0 .
7. Return the sinker to the air bath and replace it with the gas inlet tube.
8. After 5 minutes, start the air supply of gas at a gage pressure of 20.0 kPa (200 mBars) at the test temperature.
9. After 420 ± 1 s (7 min.) shut off the gas and quickly remove the inlet tube from the test vessel. Immediately start the timer and immerse the sinker in the fluid/gas dispersion. Attach the wire to the beam and maintain distance from bottom as before.
10. Determine the balance setting that will correspond to 0.2 % of gas by volume ($d_0 - 0.0017$) for air, and record the time required from shutting off the gas until the balance passes this null point. Record times of up to 15 minutes to the nearest 0.1 min, and those from 15 to 30 minutes to the nearest 1 minute. If the null point is not reached in 30 minutes, discontinue the test.

DATA: The data collected will be simply the gas bubble separation time at the test temperature. The test will be conducted three times for each sample to indicate reproducibility. Repeatability and reproducibility are reported on for both the ASTM method and the DIN method for air entrainment testing in the ASTM procedure.

PROCEDURE:

DISSOLVED AIR... The procedure for testing for dissolved air is rudimentary and is intended only to yield qualitative information concerning the possible presence of dissolved air.

SUMMARY OF METHOD: Fluid samples are placed in a vacuum flask and an aspirator is used to pull a vacuum at 628 mm Hg. The three above mentioned silicone brake fluids as well as the HDCP-470 polyglycol fluid are tested for presence of air bubbles in the fluid.

TEST METHOD:

1. Place 50 mL of fluid in vacuum flask and stopper. Attach aspirator hose and pull a vacuum of 628 mm Hg for 45 sec. Swirl the flask gently during this 45 sec and note any appearance of air bubbles.
2. Repeat the above procedure three times for a total of four trials with a total time of 135 sec under vacuum. Record observations.

DATA: The data collected will simply be a report of observations of air bubble presence over the period of time which a vacuum is applied to the sample.

RESULTS:

In concurrence with results obtained during the 1982 entrainment testing, it was found that each of the silicone brake fluids exhibited shorter gas bubble separation times than the conventional polyglycol fluids. Actual separation times are summarized as follows:

FLUID @ 25 °C	SEPARATION TIME	
	(sec)	(min)
POLYGLYCOLS		
Olin HDCP-420	222.6	3.7
Olin HDCP-470	277.4	4.6
SILICONE BRAKE FLUIDS		
GE SBF-1001	89.6	1.5
Delco Moraine SBF-1003	95.8	1.6
Dow SBF-1000	140.3	2.3

The data reported thus far pertains only to pure samples of each fluid. When a mixed fluid analysis was attempted, the solution formed a

stable emulsion. The density of a 90:10 SBF/Polyglycol solution was slightly higher than the pure SBF. After treating the sample with blown air, the density increased most likely due to the dispersion of the polyglycol throughout the silicone brake fluid. Before the air was blown through the sample, the polyglycol sank to the bottom, and a two phase system was formed. The formation of a stable emulsion precludes the possibility of obtaining air entrainment data on the mixed fluids.

The results of the vacuum testing reveal that the silicone fluids appear to contain more dissolved air than the conventional polyglycol fluid. Observations were as follows:

FLUID	TRIAL	OBSERVATION OF AIR BUBBLES
HDCP-470	1	very slight presence of bubbles
	2	" "
	3	" "
	4	" "
SBF-1000	1	moderate: dissipates after 30s
	2	apx 10ml " "
	3	" "
	4	" "
SBF-1001	1	moderate: dissipates after 30s
	2	apx 10ml " "
	3	apx 25ml " "
	4	apx 20ml " "
SBF-1003	1	slight presence of bubbles
	2	" "
	3	moderate: dissipates after 30s
	4	slight presence of bubbles

It should be noted here that the Delco Moraine silicone brake fluid (SBF-1003) exhibited a small amount of dissolved air comparable to that of the conventional polyglycol (HDCP-470).

CONCLUSIONS

From the data obtained as a result of the testing completed according to this protocol, it can be concluded that,

- 1) Entrained air, as determined by the ASTM D 3427 test, separates more rapidly from silicone brake fluid than from the conventional polyglycol fluid.
- 2) A qualitative vacuum test shows that silicone brake fluids contain slightly more dissolved air than polyglycol fluids.

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